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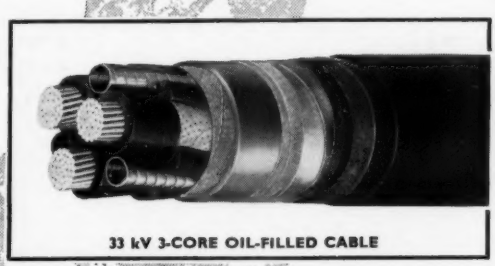

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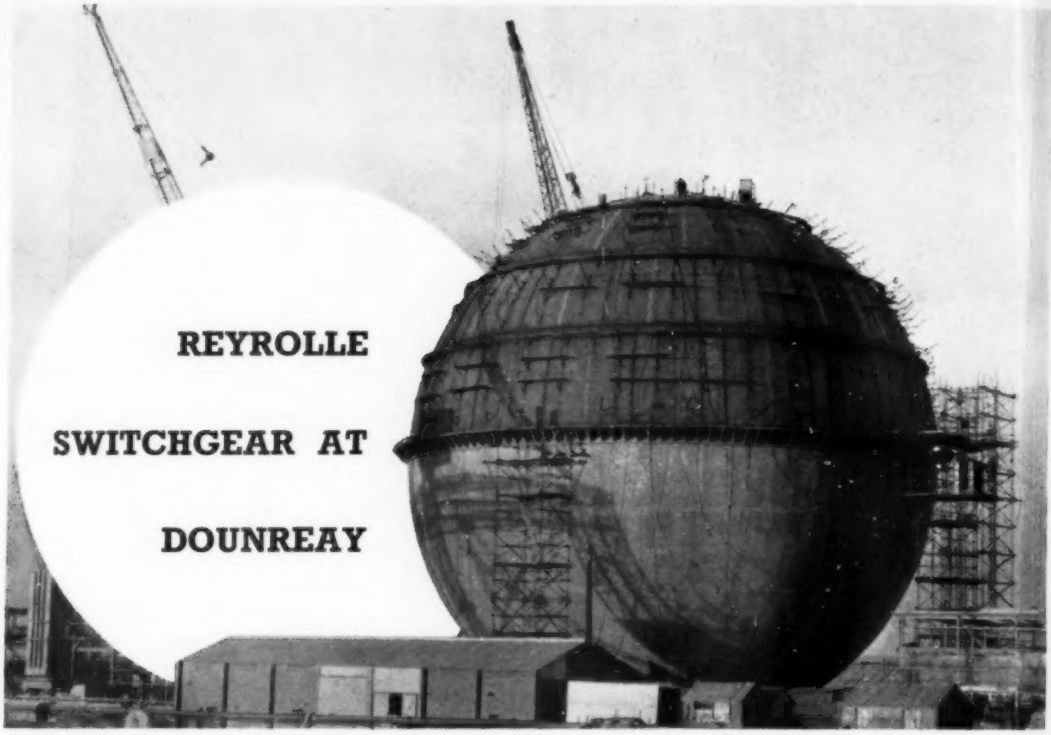

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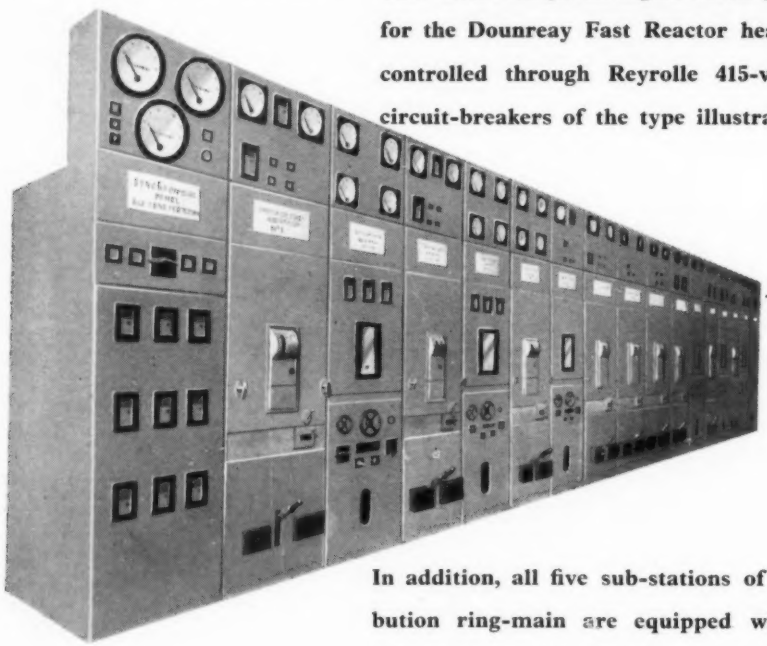

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Volume 9 Number 10

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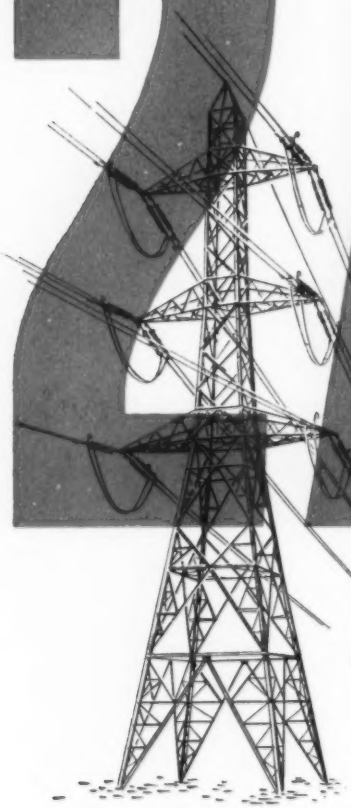

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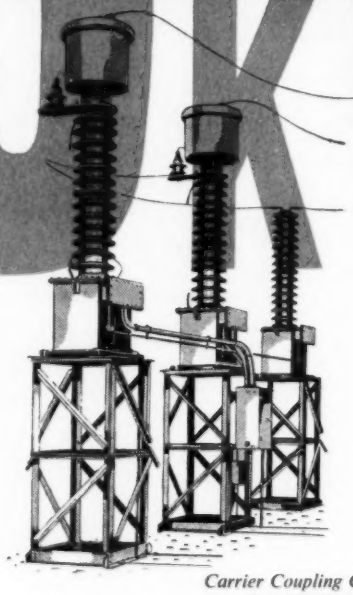

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Reorientation in Transmission

DURING the last two decades the design of generators, transformers, switchgear and other electrical plant to be found in hydro-electric power stations has become largely standardised. Improvements, of course, are always taking place, which cumulatively enhance the efficiency of generation and reliability of operation, but they are changes in detail rather than in basic design.

In the field of electrical power transmission, however, a rapid reorientation of ideas is in progress. In the United States, in France, in Sweden, and in the U.S.S.R., to mention only the leading exponents of the art of long-distance large-scale electrical power transmission, there have been proposals in the last twelve months for increasing the voltage ceiling of three-phase alternating-current transmission lines, for making greater use of existing lines at 400 kV and lower voltages, and for reducing the cost of transmission (both the capital cost and the operating cost) by applying the results of research to the reduction of insulation levels, thus making better use of the active materials. In addition, the upsurge of interest in high-voltage direct-current power transmission is remarkable. There are no less than six schemes in the world, either in commercial operation, in experimental operation, or being actively projected.

It is especially interesting to the water-power engineer to find that what he has hitherto regarded as the weakest link in the chain between generator and consumer is now receiving this increased attention. In the past, transmission lines were responsible for more failures of supply than any other part of the equipment throughout the chain. This was only natural in view of the vulnerability of the lines to lightning and to damage from such unpredictable causes as hurricane-borne tree branches, and the onslaughts of blizzards bearing sudden ice loadings, which could be released just as suddenly. It is true that as long as a transmission line is carried over the ground it will always be subject to natural hazards; but one by one the electrical hazards are being defeated, or at least controlled. For example, on the Russian 400 kV system the successful use of both single-phase and three-phase automatic reclosing after an interval of only three cycles has meant that momentary outages may well pass completely unnoticed, since the circuit would be restored before any rotating machinery had time to fall out of step.

The scientific approach to earth-wire designs, coupled with ever-increasing knowledge of earth resistances, has assisted in combating lightning outages.

Greater use of model networks and analytical equipment in power-system laboratories has resulted in more precise evaluation of the value and characteristics of internally generated over-voltages, thus resulting in a reduction in the amount of insulation necessary, decreasing capital costs, and giving greater certainty of operation under given fault conditions.

The use of high-voltage direct current is gradually being brought within the practical consideration of any engineer faced with the problem of transmitting either modest amounts of power through a submarine cable or large amounts of power over a long-distance overhead line. Economic data as to the comparison between a.c. and d.c. costs for given loads and given distances are becoming much more readily available, and in this latter respect tribute must be paid to the forthcoming attitude of the Russian engineers who are now making available to the whole world the results of their intensive technical and economic efforts in the direction of greater use of direct current.

The testing of the transformers used to step up the generation voltages to the high levels needed for bulk transmission has progressed to a stage where major transformer failures may almost be ruled out as a potential cause of interruptions to supplies. In the last five years, switchgear testing for such designs as multiple-break air-blast circuit breakers has reached a stage where it can be said to have largely passed from the empirical to the scientific; and network analysers, with the aid of greatly improved electronic computing equipment, now make it possible for extremely accurate predictions to be made of the

performance of particular circuit-breaking devices under particular network conditions, a state certainly not realised a decade ago.

Perhaps the most interesting development, signs of which have been seen recently in Russia and in Sweden, is that which leads the transmission engineers to think that without much upheaval of their transmission network, they can raise the transmission voltage from the 400 kV level to 500 kV. This will mean that a very considerable proportion of the expense attributable to the supporting structures on a long-distance transmission line will be able to bring an enhanced return during the useful lifetime of the scheme.

The need, so often stressed in these columns, to mate together the nuclear power stations of the future with hydro-electric plants of widely varying characteristics, to the great and indispensible advantage of both, will undoubtedly stimulate transmission engineers to continue along the path of research and development which they have pursued so successfully in recent times.

Benmore and Cook Strait Decisions

THE New Zealand Government's decision to proceed immediately with the construction of the Benmore hydro-electric power station in the South Island has been announced by the Minister in charge of the State Hydro-Electric Department, Mr. W. S. Goosman. Benmore, which is estimated to cost £36,400,000, is the biggest power project to be undertaken in New Zealand. Construction will be spread over seven years and first power is scheduled for 1965. The station, which is to have an installed capacity of 480 MW, is to be built on the Waitaki river. Its major feature will be an earth dam which will be among the biggest of its type in the world.

It is also hoped to lay a trial length of cable for power transmission across Cook Strait before next winter. The cable, half a mile in length, will be laid off the shore of Oteranga Bay and left there as long as possible, probably for two years, before being lifted, when it will be closely examined for mechanical damage. The investigation of British Insulated Callender's Cables Limited has shown that Oteranga Bay, in spite of much underwater rock, is quite suitable for cables, and the trial laying is to make certain that both the route and the type of cable chosen are satisfactory.

The annual publication "Statement and Annual Reports" for the year ended March 31, 1957, has now been issued by the New Zealand Ministry of Works, and a digest of the sections of the Report of the Engineer-in-Chief, Mr. C. W. O. Turner, dealing with hydro-electric developments appears on page 396 of this issue.

Conference on Turbines and Pumps

AS noted in our May issue a conference on turbines and pumps will take place at Aix-en-Provence from June 26-28, 1958, under the auspices of Société Hydrotechnique de France, and will be preceded by visits from June 23-25. The general reporters for the various sections have now been selected, and are as follows: General Introduction, M. Paul Chapouthier; Development of Turbine Technology and its Influence on Civil Engineering, M. René Langlois; Turbine Governors, M. Alexis Dejou; Turbine Efficiency and Cavitation Problems, M. Marc Henry; Turbine Applications, M. Jack Narcy; Pump-Turbines, M. Robert Gibrat; Pumps, M. Paul Bergeron; Borehole-drilling Turbines, M. René Delmas.

Persons wishing to submit papers, which must be in French, under any of these heads, are requested to advise the Société at 199 Rue de Grenelle, Paris VII, without delay, and to forward three copies of a ten-line summary not later than October 31. The papers themselves must be sent in by February 28, 1958.

British Newfoundland Corporation Projects

FURTHER news about the Hamilton River project, Labrador, is to be found in the Fourth Annual Report, to March 31, 1957, of the British Newfoundland Corporation. Studies completed in 1955, to which we have referred in previous issues, confirmed that 4,000,000 h.p. of high-load-factor power could be developed at a single site 16 miles below Hamilton Falls, and that there was a further reserve potentiality of 2,000,000 h.p. downstream. Basic designs for the power plant, control structures and other engineering works have been completed, and construction cost estimates have been independently checked and excellent agreement obtained. An access road, 104 miles long, was driven in 1956, and will be surfaced throughout for all-weather use by wheeled vehicles by the end of the present year.

A first-stage development of 1,000,000 h.p. is considered to be the most economic and will provide power at a fully competitive price; the cost of additional stages will be exceedingly low. A major effort is being directed towards finding sufficient consumer demand to justify a development.

In the Bay d'Espoir investigations are proceeding towards an integrated industrial development of the region, and the Shawinigan Engineering Co. Ltd. is carrying out a study of the hydro-electric potentialities of the district, which have been previously assessed at 280,000 h.p.

A preliminary survey of the water-power potentialities in the Burlington Peninsula area was carried out by Sir Alexander Gibb and Partners for the Corporation at the request of a mining company, and discussions are in progress to determine whether a hydro-electric development can be justified.

Power in Portugal

THE annual volume of electrical statistics issued by the Portuguese Government reveals a continuation of the remarkable growth in output during recent years and of the progressive swing-over towards hydro-electric at the expense of thermal generation. For the year ended December 31, 1956, the overall output increased by 15·1% to 2,176 million kWh, and the power produced in hydro-electric stations rose by 17·96% to 2,035·7 million kWh, whereas the output from thermal stations fell by 14·82% to 140·3 million kWh; thus upwards of 93% of the total output came from hydraulic plants.

These figures cover both public-utility and private plants, but the breakdown figures for the two types of service show significant differences. In private

plants thermal generation accounted for 75% of the total for the year, but as compared with 1955 thermal generation increased by only 9% as against 25·7% from water power. On the other hand, public utility plants derived no less than 98·1% of their output from water power, representing an increase over 1955 of 17·8% as against a decrease of 46·8% from thermal plants. Thus public supply is overwhelmingly hydro-electric, whereas in private plants thermal generation remains predominant although the proportion of hydro power is on the upgrade.

The total installed capacity in the country rose from 892 MW in 1955 to 974 MW in 1956. Of this total, hydro capacity was 759 MW as compared with 681·5 MW in 1955; thermal capacity increased by only 4 MW. The significant additions to public-utility hydro-electric capacity during the year were a 54 MW Francis set at Vila Nova, a second 22·4 MW set at Bouça and a 19 MW addition at Santa Luzia.

Loch Awe Pumped-Storage Scheme

THE North of Scotland Hydro-Electric Board have announced their Awe project which includes provision for the construction of the first large-scale pumped-storage hydro-electric development in Scotland. The scheme proposes to utilise the flow from a catchment area of 324 square miles and will be constructed in three sections—Inverawe, Cruachan and Nant—and it is the Cruachan section which will include the pumped-storage works. The total installed capacity of the scheme as a whole will be about 450,000 kW and the estimated cost £24,500,000.

The Inverawe section, which will harness the power potential of the river Awe, will involve the regulation of the level of the loch by means of a low barrage a short distance downstream from the outlet. This is essentially a regulating barrage and is not intended to raise the level of the loch, so that roads, piers and agricultural ground will not be affected by flooding. The diverted water will be taken by a tunnel to a power station situated near the mouth of the river. This station will have an installed capacity of about 35,000 kW and an average output of 101 million kWh per annum. Provision will be made for the release of compensation water into the river Awe, and suitable arrangements made for migrating fish.

The pumped-storage section at Cruachan will have a capacity of about 400,000 kW. It will be used to absorb, at night and at weekends, the surplus energy from atomic or high-efficiency steam stations by pumping water from loch Awe up to a high-level reservoir situated on Ben Cruachan at an elevation of about 1,300 ft. This reservoir will be connected by shafts to an underground power station provided with turbine pump generators; the horizontal tailrace tunnel to loch Awe will also serve as the intake for the pumps. The combined pumping and generating machines will be fed mainly by water derived from loch Awe but this water will be supplemented by intakes tapped off from high-level streams.

The Nant section of the scheme will involve the raising of the level of loch Nant by the construction of a dam near its outlet. The impounded water will be conveyed by tunnel and pipeline to a power station near Inverinan, on the shore of loch Awe. The station will have a capacity of 18,000 kW and an estimated annual output of 27 million kWh. This scheme will necessitate short diversions of the public road from Dalmally to Oban, but arrangements will be made to ensure that this thoroughfare will remain open throughout the construction period.

Mexican Hydro Programme

THE Mexican Comisión Federal de Electricidad has nearly completed a 135 MW plant at Tingambato, at a cost of $1,200 million. This will be the fifth plant on the Miguel Aleman hydro-electric system and will raise the aggregate capacity to 350 MW.

The Comisión is also constructing a hydro-electric plant of 162 MW in Apulco, Puebla, and another of 154 MW in the State of Oaxaca, apart from a 74 MW plant in Michoacan and 16 others of various types (hydro-electric, thermo-electric and diesel) in other states of the Republic, with a total capacity of the plants under construction of 552 MW. By the end of 1958, the Comisión will have at its disposal more than 1,000 MW, which, however, will be insufficient to satisfy the growing industrial development of the country.

Lower Engadine Scheme Recommended

A SCHEME by which the waters of the river Inn can be used for the development of hydro-electric power has now been approved by the Swiss Federal Government, in agreement with the Italian electricity authorities. A previous scheme which involved the construction of a dam on the river Spöl has now been abandoned, as there were strenuous objections by various naturalist societies to the flooding of parts of a national beauty spot which formed the habitat of interesting groups of Alpine fauna and flora. In the new scheme the Spöl will be diverted by a weir and associated tunnel to the Adda river in northern Italy and the power development will be shared by both countries.

Snowy Scheme Agreement

AFTER some years of negotiations on details, a draft agreement on the use of electricity and water from the Snowy Mountains scheme has been drawn up for submission to the Australian Commonwealth, New South Wales and Victorian Parliaments. The Government of Victoria has approved the agreement in general, subject to clarification of certain points regarding the possibility of flooding on the Upper Murray River.

According to Mr. G. O. Reid, Minister of the Electrical Undertakings in Victoria, Snowy power would be shared on the basis of two-thirds to New South Wales and one-third to Victoria, after the Commonwealth had taken what electricity it required from the scheme for use in the Australian Capital Territory and in and near the Snowy Mountains area. Commonwealth requirements were not expected to be large. As far as practicable, the State Electricity Commission of Victoria and the Electricity Commission of New South Wales would be permitted to take their respective shares of electricity when it best suited their needs. They could each draw on the scheme at any time during the day, month or year as it suited them, and might even accumulate a reserve entitlement, or draw in advance of their entitlements. The

only limiting proviso was that they should not adversely affect the interests of other parties to the scheme.

Broadly, the financial clauses ensured that the cost of electricity to Victoria and New South Wales would be no greater by taking Snowy electricity than it would have been had each State continued to rely solely on its own resources.

The Snowy scheme would begin to supply some electricity to Victoria in 1959. Initially, the output available to Victoria would be only 25 MW of peak-load power, but this share would progressively increase to 200 MW in 1963. The capital cost to the State if it had to provide an equivalent amount of thermal plant and related coal production assets would be some £25 million. Looking further ahead to the completion of the scheme—about 25 years hence—Victoria's share would be over 900 MW.

Work was already in hand, Mr. Reid said, on the 62 miles long 330 kV power line to connect the Victorian system with the Snowy scheme. It would run from a new switching station at Dederang (near Kiewa) to the River Murray a few miles south of Towong, where it would connect with another 330 kV power line from the Snowy Mountains scheme.

Viewed as an irrigation scheme, Mr. Reid said, the Snowy project would provide an extra 400,000 acre ft. of water a year diverted into the Murray, which would be shared by Victoria and New South Wales.

The draft agreement has also been laid before the N.S.W. Cabinet by Mr. Renshaw, Minister for Local Government, who said that the scheme was expected to make a maximum contribution of 13 or 14 per cent. to the N.S.W. electricity group.

Ontario Increases Capacity

THE Hydro-Electric Power Commission of Ontario have decided that a fourth 200 MW generating set shall be added to the Richard L. Hearn Station, Toronto, and be put into commission by the year 1960. At present the station is operating on four 100 MW units but next year the first of the 200 MW sets will be ready to put under power and will be followed by three more similar sets, bringing the ultimate installed capacity up to 1,200 MW.

The Commission have also made a start on their Silver Falls project, some 25 miles north-west of Port Arthur, Lake Superior. This station will operate a single 43,500 kW set which will be remote controlled and is expected to be ready by the end of 1959.

Power in Uganda

THE Uganda Electricity Board is already considering a second power station on the Nile as it has become tolerably clear that the Owen Falls station will not be able to supply all the electricity required by 1965. The economic position in regard to further power demands has been investigated by The Economist Intelligence Unit and a report has now been issued. It suggests that a substantial increase in the national income may be expected to take place in Uganda during the next 15 years and that this increase will necessarily have to be supported by a larger power output. There is little possibility, the Report adds, of adding to power production by means of small-scale plants, as the conditions do not exist for them, and the only solution is to construct a completely new dam across the Nile and bring generating sets into commission successively, as they are required. The difficulties in regard to the capital required are foreseen, but it is concluded that no other constructional project is more likely to be a better investment for Uganda and its peoples in the long run. In short, the construction of a further large hydro-electric station is considered to make the shortest cut to greater prosperity.

New Hydraulics Laboratory for Sydney

A FRESH development in the expansion of research by the Australian universities takes the form of a new hydraulics laboratory to be added to the N.S.W. University of Technology. The laboratory, which will be the first of its kind in Australia specially equipped and designed for the work, will be opened later this year. Research and industrial investigation will be carried out on irrigation, ventilation, engineering, dam construction and air-pollution problems, and, if funds are available, on river erosion as well. The laboratory will cost £A30,000 and will cover 9,000 sq. ft. of floor space.

Further Turbines for Table Rock

ENGLISH Electric Export and Trading Co. Ltd. has received from the U.S. Army Corps of Engineers a further order for Table Rock power station, White River, Missouri. The new contract is to supply numbers three and four water turbines. The first two turbines of similar design and power were ordered from English Electric in November 1954 and are now nearing completion in the company's works at Rugby and Netherton, near Liverpool. A year later the company was given an order to supply a transformer (90,750/121,000 kVA, 13·2/161 kV three-phase, 60 cycles) with all accessories and spare parts for the switchyard at Table Rock dam. The output of the water turbines is 68,000 h.p. at 128·6 r.p.m. under a 190 ft. head and they are of the vertical Francis type.

The Sluice Gate

SO far as can be gleaned from the scanty records which have come down to us of Roman engineering feats, the first mention of a sluice gate for controlling the flow of water appears in the year 257 B.C., in the time of Cato. This consisted of a wide plank of elm which was raised and lowered between two guide slots on much the same principle as the hand-operated sluices which controlled the water-driven corn mills right up to the middle years of the 19th century. The use of cast iron for sluice gates appears to date from the year 1701, when reference is made to one erected in France. The advantages of using cast iron instead of wood are obvious and it was not long before a similar iron sluice was installed at an English mill, near Windsor in 1720.

It is interesting to reflect that the many complicated designs in use today had their origins in such early times. The word itself comes down to us from the Low Latin *exclusa* (aqua), to shut out water, and appears in its more modern orthography in the Old French *escluse* or *esluice*, from which the English corruption, sluice, is very obvious.

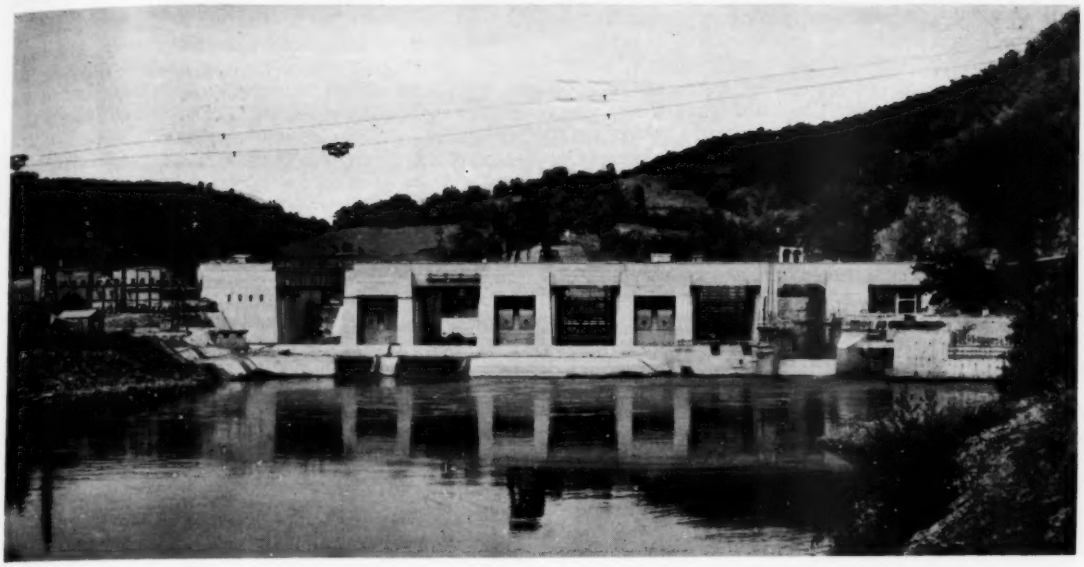

Fig. 1. Argentat power station in course of construction

Argentat

The Argentat station on the Dordogne, in addition to its normal use for public electricity supply, has been conceived by Electricité de France as a " guinea-pig " station for full-scale tests on tidal-power units in preparation for the Rance development

THE contribution made by Electricité de France to the study of tidal power has been so outstanding that it must have caught the imagination of engineers all over the world. The extent of this contribution became evident at the Conference on Energy from the Sea held in Paris last year,* and fittingly enough, it is Electricité de France that has commenced the construction of the world's pioneer tidal-power development on the Rance estuary.

This development has been rendered possible by one vital factor — the development of a horizontal Kaplan-type turbine-alternator unit suited for very low heads and capable of operating either as a turbine or as a pump with the water flowing in either direction. Such a unit offers the first real solution to the problem of the intermittent character of the tides; and this, coupled with the fact that the savings in capital cost both of the units themselves and of the associated civil-engineering work are so substantial, has transformed the economics of tidal power.

Naturally, a design of unit such as that proposed for the Rance does not come straight from the drawing board but is the outcome of a process of development and experiment. The tubular type of turbine may be said to have originated with the 1919 and 1924 patents of the late American consulting engineer, Mr. L. F. Harza, who proposed a horizontal runner surrounded by a ring which carried the alternator poles, the alternator thus forming an annulus round the water passage. This principle was subsequently developed by Arno Fischer in Germany and by Escher Wyss in Switzerland.†

The problem of sealing the joint between the runner ring and the casing led to various designs providing other locations for the alternator. Two solutions in particular proved to be significant. The first was to install the alternator in an open pit; the second was to construct a combined turbine-alternator unit in which the alternator was housed in a "bulb" completely surrounded by water. The pit design was studied by the Neyrpic organisation at the request of la Société d'Etudes pour l'Utilisation des Marées, and the first bulb design, in two units each of 265 h.p., was installed by Arno Fischer at Rostin. One of the most recent bulb-type installations is at the French Railway's generating station at Castet on the Ossau, where two 1,100 h.p. units have been in service since 1953. These sets incorporate induction generators cooled by oil.

It was against this background that Electricité de France selected 9,000 kW bulb-type units for the

* *See* WATER POWER, November and December 1956, pp. 428 and 457.

† *See* "The Tubular Turbine," by H. C. von Widdern, WATER POWER, January 1955, p. 15.

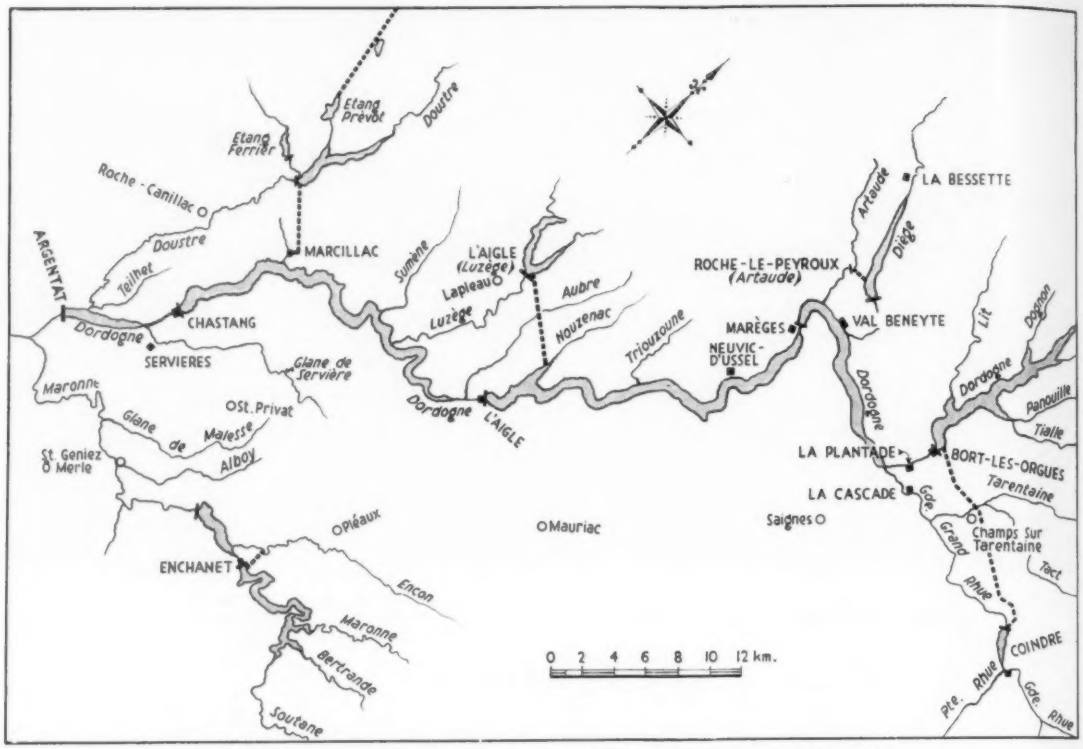

Fig. 2. Map of the Dordogne showing the location of Argentat station

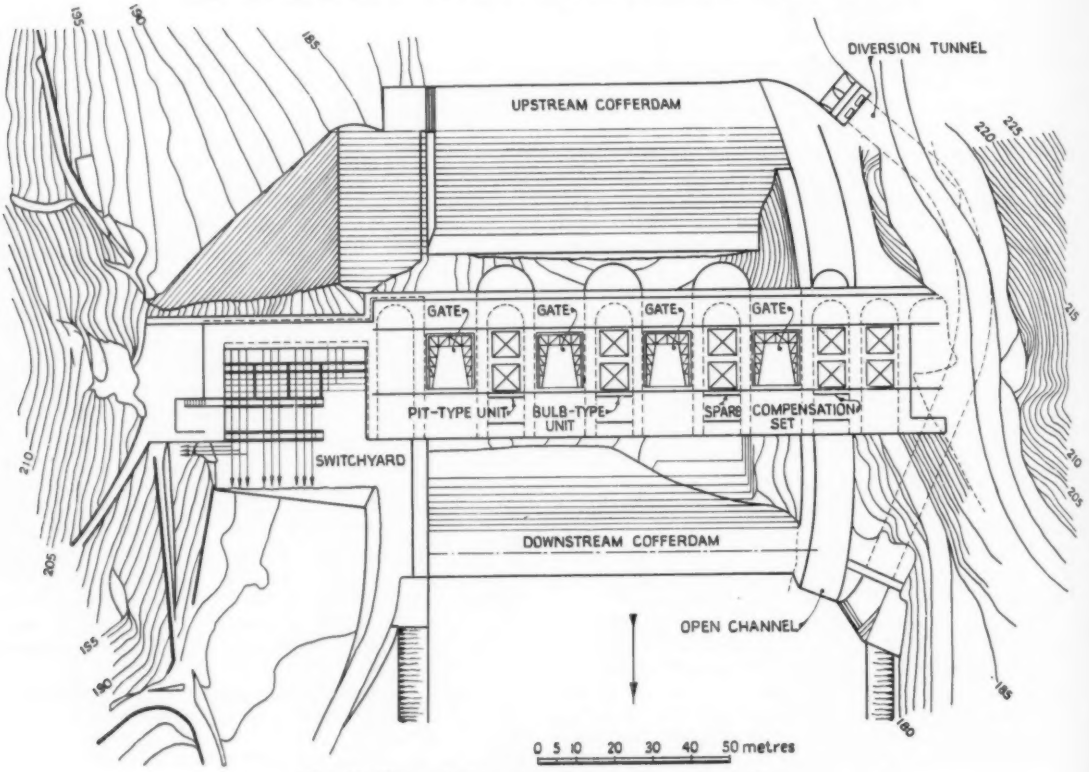

Fig. 3. Plan of Argentat dam and power station

Rance scheme. Nevertheless, such units represented a great increase in capacity on anything of this type hitherto constructed, and Electricité de France were anxious to test out designs of comparable size under practical operating conditions before finalising the design of the Rance machines. They therefore decided to build the Cambeyrac station on the Truyère and the Argentat station on the Dordogne as experimental plants for this purpose in addition to their normal use for public electricity supply. At Cambeyrac Ets. Neyrpic have installed a 9,400 h.p. bulb-type unit operating under a head of 10·75 m., and at Argentat the same organisation has installed a bulb-type unit of 20,000 h.p. under a head of 16·5 m. A pit-type unit of similar capacity has been supplied by Alsthom-Charmilles, and space is reserved for a third set of one or other of these types. Both sets have been designed, and the station has been laid out, to enable tests to be carried out with the units operating as pumps, as well as tests under normal operation as turbines.

It is the Argentat station which forms the subject of this article, and more detailed reference to these sets will be made later, but we have felt it necessary to explain at the outset the significance of Argentat in its bearing on the design of tidal-power plants.

The Dordogne

The Dordogne has its source on the north flank of the Puy-de-Sancy, the highest point of the Auvergne mountains in the Massif Central, and flows in a south-westerly direction through granitic and phyllitic gorges a distance of 144 km. to its confluence with the Maronne just below Argentat at an altitude of 173 m. There it emerges into an alluvial plain and flows a further 340 km. to discharge into the Garonne.

At Argentat the catchment area is 4,412 sq. km., the average total annual run-off is 3,450 million cu. m., and the average discharge, as determined by records between 1918 and 1947, is 109·4 cu. m. per sec. The flood period extends from November to May, save for a period during the winter frosts, and low flows prevail from June to October. An average annual flood flow of 800 cu. m. per sec. is attained, but the regime is characterised by sudden fierce floods. For instance, in December 1952, in spite of the regulation effected by the upstream stations to be mentioned in a moment, a flood was experienced at Argentat of 1,970 cu. m. per sec., which attained its maximum in a few hours. Previously, in 1866, a flood of 2,000 cu. m. per sec. was recorded, and in 1944 there was a flood which in the absence of regulation would have amounted to 2,800 cu. m. per sec. It has therefore been considered necessary to design the Argentat station for a catastrophic flood of no less than 4,000 cu m. per sec.

The Argentat development forms the final stage in the exploitation of the Upper Dordogne. Referring to the map, Fig. 2, the developments in the main bed of the river, reading from upstream, are Bort-les-Orgues, Marèges, l'Aigle, and Chastang. Turning now to the tributaries, a left-bank tributary, the Grande Rhue, has two reservoirs in its upstream branches, the Grande Rhue and the Petite Rhue, which supply a station at Coindre, and the discharge from this station is impounded and transferred to the Bort reservoir. On the right bank there is a dam at Roche-le-Peyroux on the Diège feeding a station at Val Beneyte, and a dam on the Triouzoume supplying a station at Neuvic d'Ussel. Farther downstream the headwaters of the Luzège are diverted to the l'Aigle reservoir, and a dam on the Doustre at La Valette supplies a station at Marcillac.

A total live storage of 700 million cu. m. is impounded in these developments, corresponding to about 20% regulation. The installed generating capacity is 855 MW and the potential annual production in a year of average flow is 2·2 million kWh.

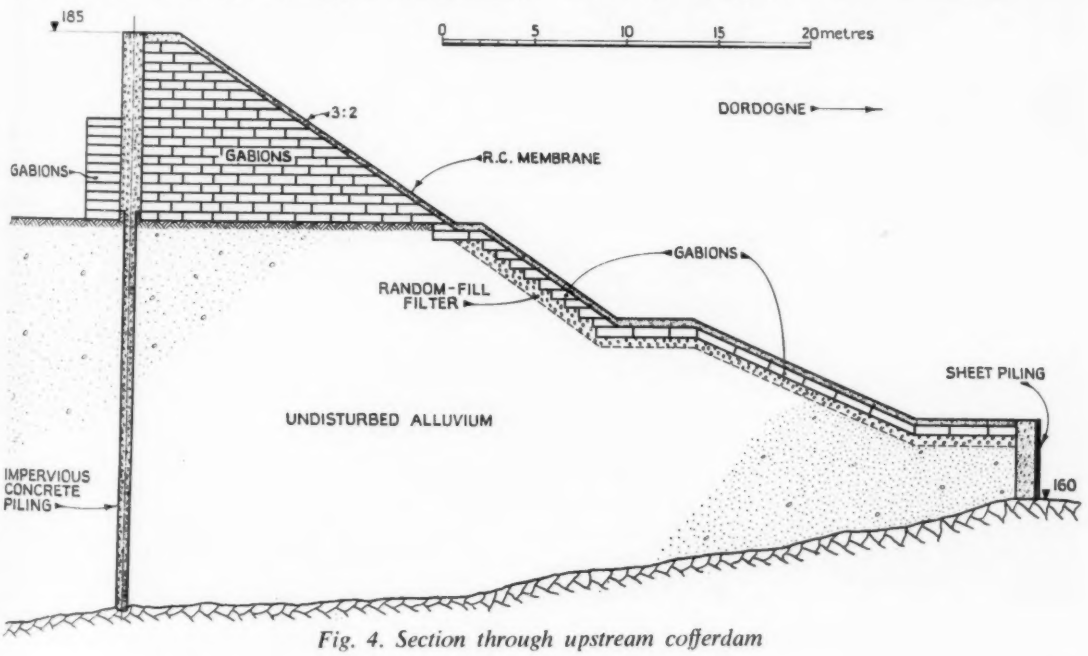

Fig. 4. Section through upstream cofferdam

The Argentat Development

The Argentat development is about 6 km. downstream of Chastang and about 2 km. upstream of the town of Argentat. A total storage of 7·2 million cu. m. is impounded, of which 5·5 million cu. m. is useful capacity, the retention levels ranging from 192 m. maximum to 185 m. minimum and the net head on the machines from 16·5 to 12 m. Two 14 MW units are installed, and space is available for a third of similar capacity.

When completed, the station will be capable of generating 92 million kWh in a year of average flow, but against this must be debited a loss of capacity at Chastang of 8 million kWh due to the Argentat reservoir backing up against the Chastang tailwater. On the other hand, the transfer that will be possible of off-peak to peak generation will permit the production of 18 million revalorised kWh.

The Argentat development should lead to a better utilisation of Chastang. In point of fact, Chastang is subject to a very strict regime of flood discharge on account of the danger that would otherwise accrue to downstream interests, but when Argentat is in service it will be possible to run Chastang at full output without restriction; thus Argentat will revalorise Chastang.

We have already explained how the design of the station centred round its use as a test installation for tidal-power type generating units, but a brief account of the steps by which the final layout was determined will be of interest. In all the schemes considered, the need to provide for a flood discharge capacity of 4,000 cu. m. per sec. was, of course, a vital consideration.

At the outset, the classical run-of-river layout embodying a power station with vertical Kaplan sets towards the right bank and a dam and spillway towards the left was ruled out in view of the excessive excavation cost that would have been incurred. Indeed, it was soon accepted as a principle that the station itself should evacuate the floods and that excavation should be confined to that necessary to secure this end. This gave rise to the idea of housing vertical sets in piles set between spillway sections, and various model tests were carried out on this basis with successful results.

It was at this stage that the suggestion was made to use Argentat as a means of testing full-scale units suitable for tidal power, and the question arose as to the type of unit to be installed. The Arno-Fischer type of tubular turbine encircled by the generator was considered unsuitable for the large capacity envisaged. It was thought difficult to design a circumferential joint to withstand the high peripheral speed called for, and in fact the rim might be too large to be machined. Further, the attachment of the runner blades to the rim to transmit the necessary power proved a difficult mechanical problem.

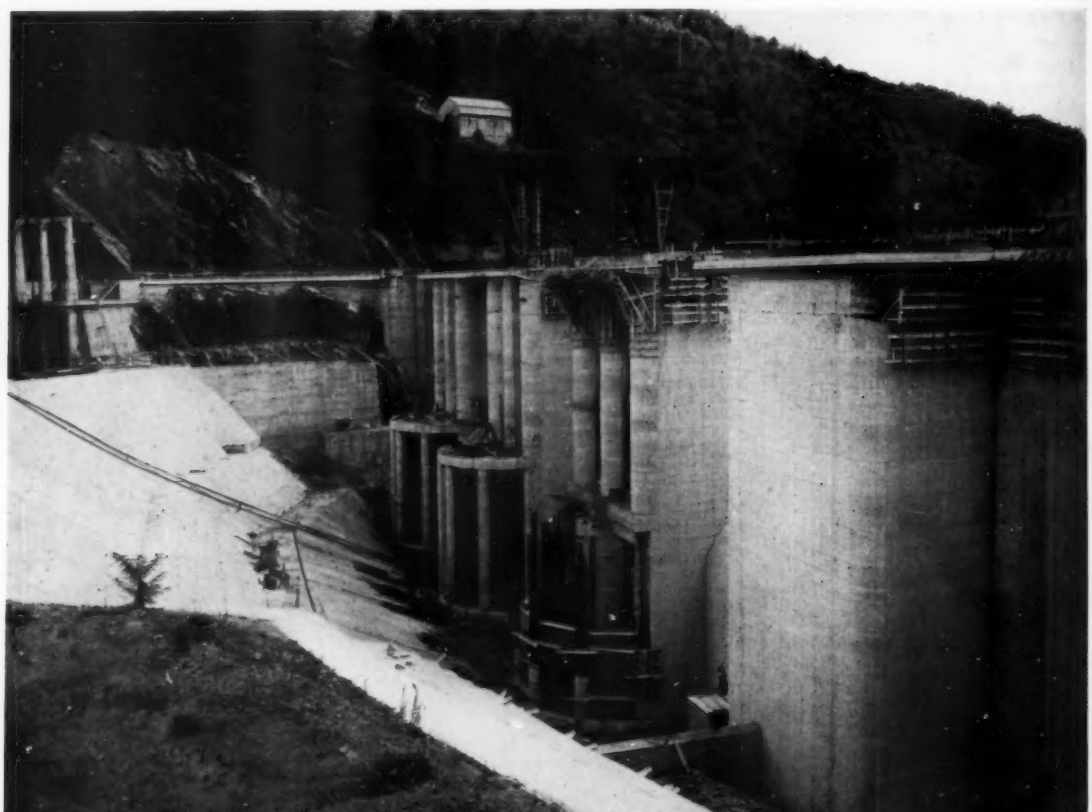

Fig. 5. Upstream side of dam, showing intakes and upstream cofferdam

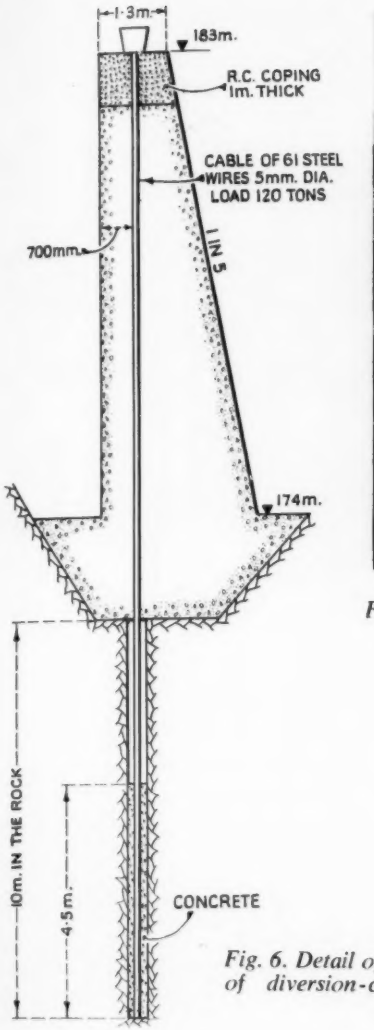

Fig. 6. Detail of prestressing of diversion-channel wall

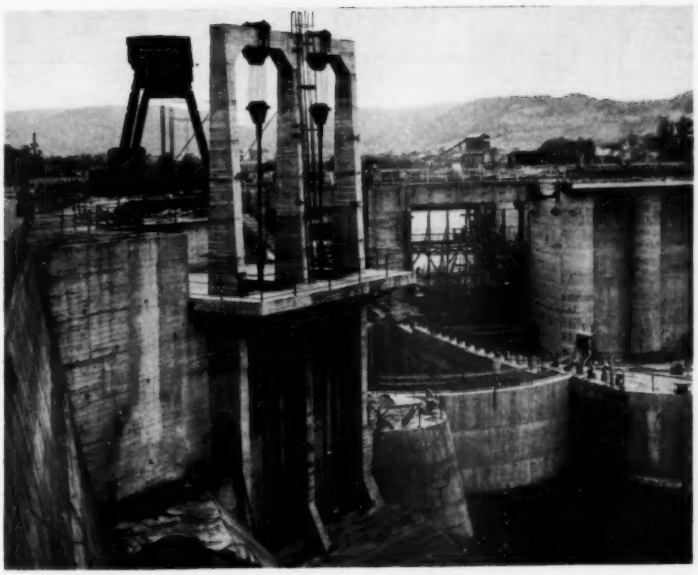

Fig. 7. Upstream view showing the diversion-tunnel gates, the diversion channel, and the prestressed-concrete channel wall

Next, the upstream bulb type of unit was considered, and a scheme was worked out, only to encounter difficulties. It appeared that the bulb alternator would have to be located in the pile upstream of the face of the dam, where it would be outside the span of the gantry crane and difficult to handle. Further, the head of the pile would have to be thickened to accommodate the alternator, and this would aggravate already bad hydraulic conditions at the water intake, which would be in the form of two convergent passages behind the bulb. Again, for hydraulic reasons it was desirable to place the turbine runner nearer to the entry than to the discharge, and an upstream bulb alternator would thus have the effect of lengthening the pile structure in an upstream-downstream direction.

At this stage Ets. Neyrpic suggested that the bulb alternator should be located downstream of the turbine. In this position there would be plenty of room for it without lengthening the pile structure, and the way would be left open to design an intake structure operating under the most favourable conditions. Also, both the turbine and the alternator could be readily handled by the gantry crane. A downstream-bulb design was therefore adopted for one unit.

At this time the claims of the "pit" design were also being investigated by Electricité de France, and it was decided that the second unit should be of the downstream pit type, the space for the third unit being left so that either a bulb or a pit design could be installed.

The pit design presents the advantage of using a standard alternator which is permanently accessible for inspection. On the other hand, the discharge passage from the turbine bifurcates and passes round either side of the pit, and in the case of a large-capacity machine at very low head the necessary size of the alternator tends to make this bifurcation excessively divergent, adversely affecting the hydraulic conditions. A possible solution to this difficulty is the use of a speed-increasing gear between the turbine and the alternator, and to investigate this point it was decided that at Argentat the compensation-water set, which is of 3 MW capacity, should be provided with a 1 : 5 epicyclic speed-increasing gear, giving a turbine speed of 300 r.p.m. and an alternator speed of 1,500 r.p.m.

A final point of interest lay in the method of control of the water flow, it being decided to place the automatic sluices on the downstream side of the sets instead of upstream as is more usual. This involved accepting somewhat higher stresses in the station structure, but was done to avoid possible vibration due to the closing of an upstream sluice. Upstream stoplogs are provided to enable any set to be dewatered.

The station layout, a plan of which is given in Fig. 3, is the logical outcome of the foregoing considerations. Essentially, the structure consists of four mass-concrete spillway sections controlled by sector gates and separated by three hollow piles which contain

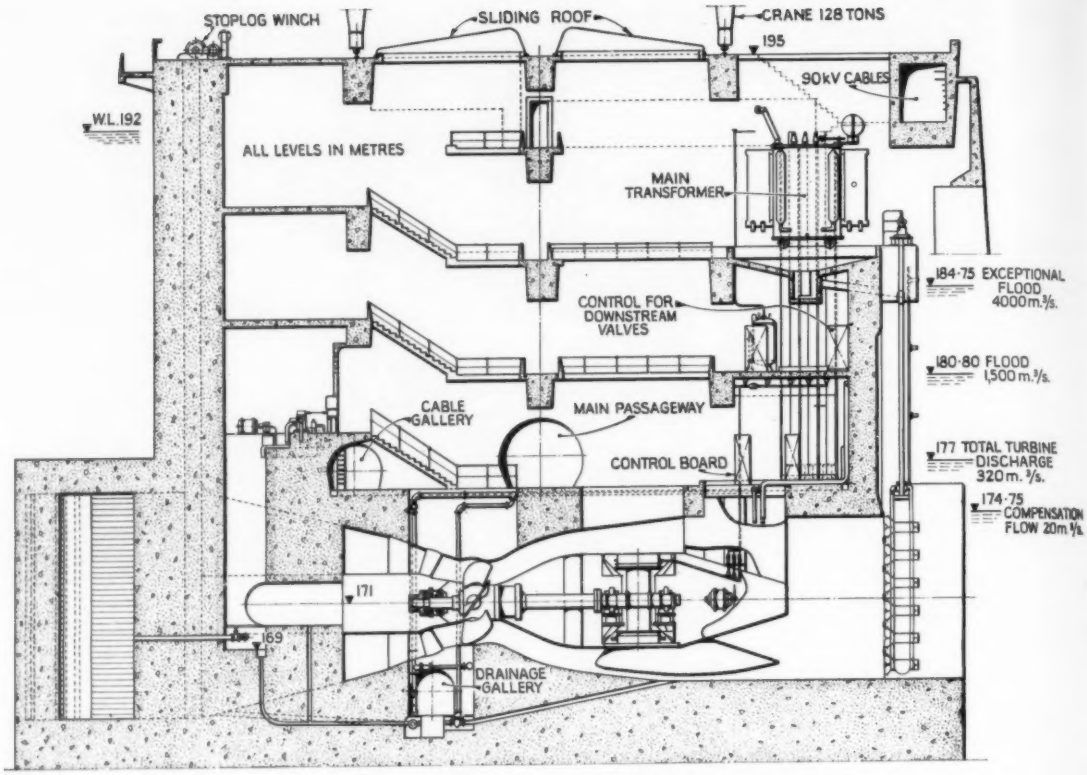

Fig. 8. Section of station taken through the bulb-type unit

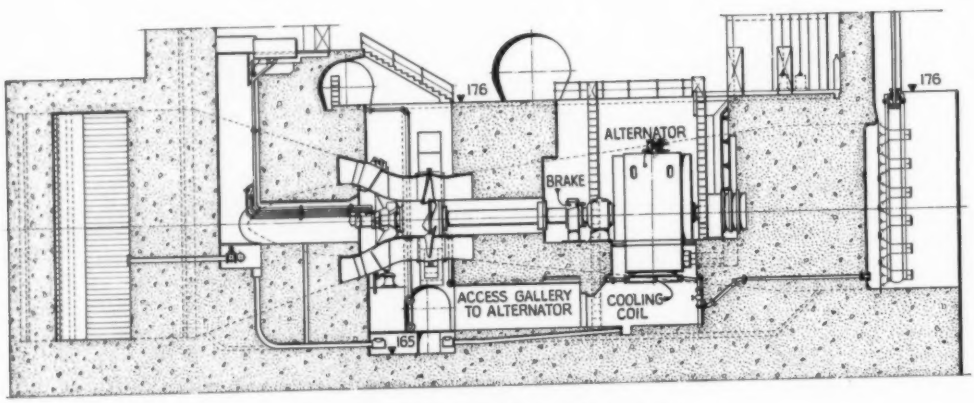

Fig. 9. Section through the pit-type unit

the main generating sets. On the left, an outer pile contains the compensation-water set and the dismantling and maintenance bays; on the right, the outer pile houses the drainage pumps, station auxiliaries and electrical apparatus, this pile being connected to the right bank by a length of concrete gravity dam. Three solutions were considered for this section: an earth dyke, a multiple-arch dam, and a concrete gravity dam. From the standpoint of cost the three solutions were more or less equivalent, and the solution was chosen which appeared to be the easiest to construct.

The outdoor switchyard is located on the downstream side of this gravity section.

Geology and Civil Engineering

On the left of the dam site the river bank consists of a steep spur of rock scoured by the river and forming an excellent abutment, but the right bank slopes gently down to the river and is covered with 15-20 m. of alluvial deposit. Below the river bed the strata are greatly disturbed, and the formation was studied by means of 24 boreholes representing 572 m. of boring.

Diversion of a river subject to a flood regime such

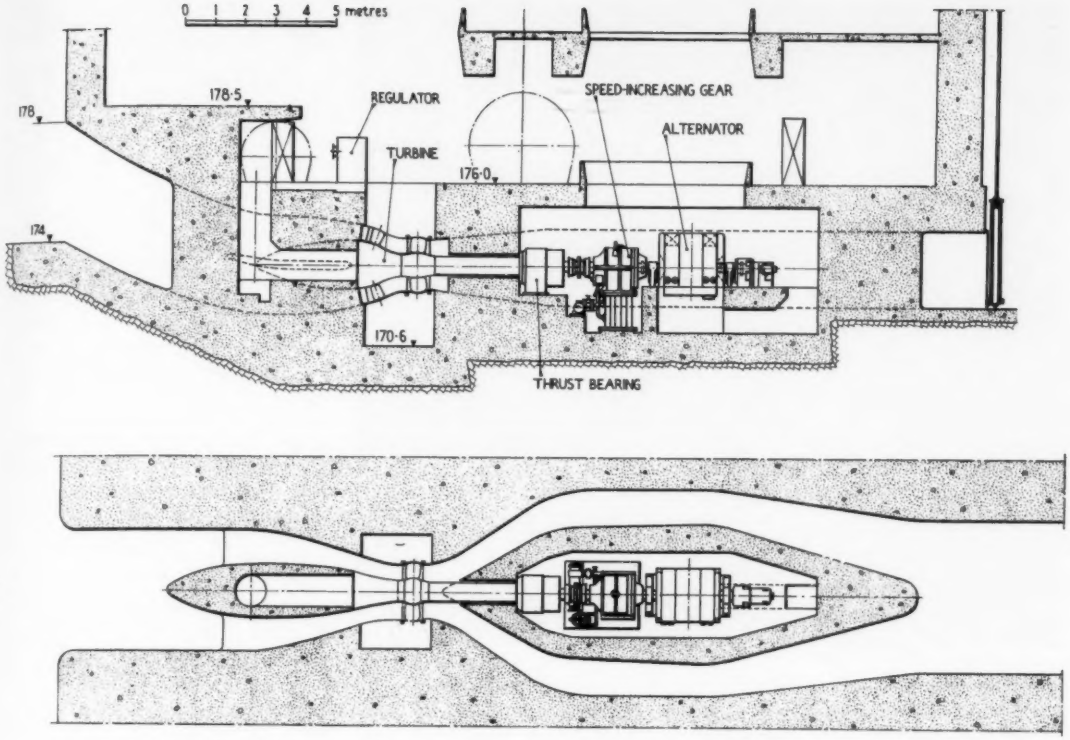

Fig. 10. Sectional elevation and plan of compensation set

as we have described required special precautions In the first place a diversion tunnel, 33·8 sq. m. in section and 132 m. long, was driven through the rocky left bank to handle flows up to 300 cu. m. per sec. This sufficed to pass the total discharge from the two machines installed at Chastang, immediately upstream, but to deal with floods in excess of this discharge an open channel was cut along the left bank on the site of the future extreme left pile, and was completed to a section 10 m. by 10 m. by a concrete wall extending from the upstream to the downstream cofferdam on the river side of the channel. This wall was prestressed by vertical cables anchored into the rock on the principle developed by Mons. André Coyne when raising the Cheurfas dam in Algeria and subsequently applied elsewhere. The cables are spaced at centres ranging from 1·2 m. upstream to 2·2 m. downstream in accordance with the load to which the corresponding section of wall is subjected. Each cable is anchored in the rock to a depth of 10 m. and exerts a pull of 120 tons. A prestressed type of wall was decided upon in view of the limited space available. Thanks to this system the wall is only 3 m. thick at the bottom, whereas a plain gravity wall would have had to be 8 m. thick to stand the water pressure. A section though the wall is given in Fig. 6, and Fig. 7 shows the diversion channel and the prestressed wall.

This channel has a capacity of 650 cu. m. per sec., and there is thus total provision for a flood of 950 cu. m. per sec., which is 150 cu. m. per sec. above the normal maximum annual flood.

Special interest attaches to the design of the upstream and downstream cofferdams, as the problem was to seal a river bed with a deep alluvial deposit without incurring excessive excavation costs. A section through the upstream cofferdam is given in Fig. 4; the downstream cofferdam is similar in principle although different in detail. To seal off the alluvial deposit an impervious wall was formed of concrete piles. Each pile was formed by boring a hole, 0·5 m. in diameter, down to bedrock by means of the mud-flush process, using bentonite as the heavy medium, and subsequently filling the hole with concrete. Alternate piles were first put down, spaced at 0·95 m. centres so that the spaces between piles were only 0·755 m. Piles, 0·5 m. in diameter, were then put down in these intervening spaces, the result being a solid curtain formed of piles overlapping in plan. This curtain was then continued above ground to the required height as a plain concrete wall, and the cofferdam was built up to section by setting concrete gabions. A filter of random rubble was set below the gabions where the alluvial deposit was cut away, and the face of the cofferdam was made watertight by a reinforced-concrete membrane.

Even with this construction some difficulty was experienced with the upstream cofferdam, for an undetected pocket of fine sand under the right bank ran out under the water pressure and endangered the structure. A liberal use of grouting remedied the situation and the cofferdam was successfully restored.

A further necessary piece of preparatory work was to form a discharge channel for the station by drag-scraping the river bed downstream for a distance of 1 km. About 300,000 cu. m. of spoil was removed, and the river bed was lowered by 2·5 m.

Fig. 11. The bulb-type unit in course of erection

Mechanical and Electrical Equipment

We have already mentioned most of the mechanical and electrical equipment in general terms, and it now remains to fill in a few details.

The sector gates were supplied by Ets. Neyrpic. Each is 12 m. wide and 11·5 m. high, and is controlled by two winches, one on either side of the gate, coupled together to ensure an even lift.

The bulb unit was designed and built by Ets. Neyrpic in conjunction with Ste. Alsthom, who supplied the alternator. A section through the station on the line of this set is given in Fig. 8.

A number of special problems had to be solved in the design of what is at present by far the largest bulb-type unit in existence, and the need for the set to function either as a turbine or as a pump presented further complications. Great care had to be taken to ensure hydraulic stability, and the thrust bearing had to be suitable for rotation in either direction. The governor and oil pumps are located on the ground floor of the station to provide centralised automatic lubrication. A view of the turbine in course of erection is given in Fig. 11, and the guide-vane assembly in the maker's works is seen in Fig. 12.

One of the major problems in the design of the alternator was that of cooling. When the upstream-bulb design was under discussion, Neyrpic/ Alsthom considered the use of oil as a cooling medium, as they had successfully adopted this system at Castet, but the proposed location of the generator gave rise to practical difficulties. Hydrogen was also considered but rejected on the score of cost. On the adoption of the downstream-bulb design it was decided to cool the alternator by air, using a separate motor-driven fan in the nose of the alternator bulb. It remained an open question, however, whether it would be preferable to use compressed air or air at atmospheric pressure, and the unit has been designed so that it can be tested under both conditions.

The alternator bulb is supported on a fairing resting on the floor of the water passage, and a streamlined access shaft in welded steel plate descends from the station floor to the nose of the bulb. This shaft also serves to carry the busbars, which rise to a three-phase transformer on an upper floor. This alternator is rated at 14·5 MVA, 0·97 p.f., 5·2 kV, 150 r.p.m.

A section through the pit-type set in the first pier is given in Fig. 9. The turbine was built by Alsthom-Charmilles, and had to comply with similar design requirements to those for the bulb turbine, but it does not correspond with the Neyrpic design, as each manufacturer solved the problem in his own way. Differences of detail, of course, are apparent; for example the thrust bearing is downstream of the alternator, whereas in the bulb-type set it is upstream of the turbine. The pit casing is seen in course of erection in Fig. 13.

The alternator was supplied by Ets. Jeumont, and as it operates in an open pit is of normal design. It has a flywheel effect of 500 ton-m^2, and is rated at 16 MVA, 0·875 p.f., 5·2 kV, 150 r.p.m.

Sections through the compensation water set are given in Fig. 10. It is a pit-type unit, the turbine having been supplied by Alsthom-Charmilles and the alternator by Schneider-Westinghouse. It is rated at 3·4 MVA, 0·85 p.f. We have already mentioned the

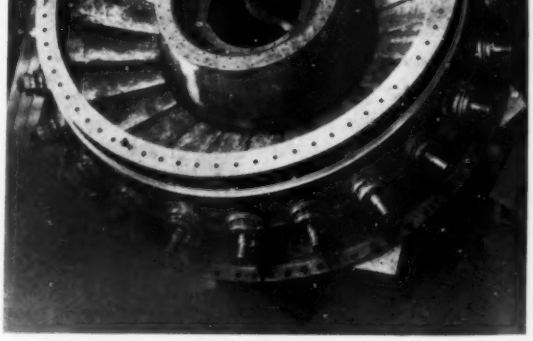

Fig. 12. Guide-vane assembly of the bulb-type unit in the works

1:5 speed-increasing gear, giving a turbine speed of 300 r.p.m. and an alternator speed of 1,500 r.p.m. The alternator is designed for a runaway speed of 4,200 r.p.m., but a device is being tested which will automatically disconnect the alternator in the event of the turbine overspeeding. Should this device prove reliable it will enable a geared alternator to be designed for a far lower runaway speed than is now possible.

The rated discharge of each of the main units is 100 cu. m. per sec. and that of the compensation set 20 cu. m. per sec., so that the completed station will have a maximum rated discharge through the sets of 320 cu. m. per sec.

Each of the sets has its own three-phase transformer stepping up to 90 kV. Oil-filled cables connect the high-voltage side of the transformers with the outdoor switchyard. The entire station will be remote controlled from Chastang, but it can eventually be controlled on site from a relay point interposed between the sets and the telecontrol.

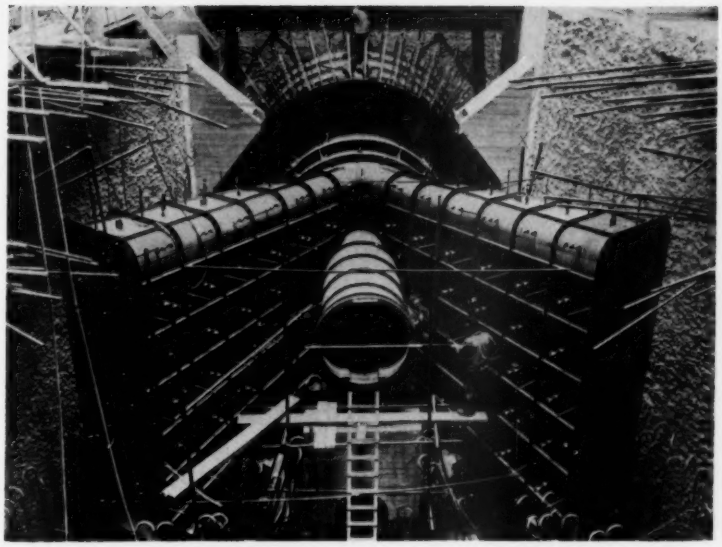

Fig. 13. The pit-type unit in course of erection

Tests

When the full series of tests has been concluded, information should be available of the utmost value in the design of low-head tidal-power units. As already mentioned, the Argentat units have been designed so that they can operate for test purposes as pumps, and to enable these tests to be carried out the cofferdams will be temporarily retained at their full height to provide a closed basin on either side of the power house, the diversion channels being left in service. When the pumping tests have been completed, the upstream cofferdam will be lowered to 181 m. and the downstream to 174 m. At the final level of the upstream cofferdam flows up to 300 cu. m. per sec. can discharge through the diversion tunnel, which will be permanently controlled by a sluice.

Contractors

The following is a list of the principal contractors concerned:—

Civil Engineering	
Dredging	Olivier et Lantrua, Clermont-Ferrand.
Main constructional work	Société Générale d'Entreprises, Paris.
Grouting and pile curtain	Solétanche, Paris.
Cranes	
128-ton portal crane	Ets. Delattre et Frouard, Paris.
10-ton travelling crane	Ferrand et Frantz, Villeurbanne.
Turbines	
Bulb set	Ets. Neyrpic, Grenoble.
Pit and compensation sets	Ste. Alsthom, Belfort.
Alternators	
Bulb set	Ste. Alsthom, Belfort.
Pit set	Forges & Ateliers de Constructions Electriques de Jeumont, Jeumont.
Compensation set	Schneider - Westinghouse, Paris.
Speed-increasing gear	Fried. Krupp, Essen.
Gates	
Upstream stoplogs	Ets. Neyrpic, Grenoble.
Downstream sluices	" " "
Sector gates	" " "
Drainage Pumps	Schneider - Westinghouse, Paris.
Lighting and Equipment	Dynalum, Paris.
Transformers	Le Transformateur, Petit-Quevilly.
	Ste. Savoisienne, Aix-les-Bains.
	C.E.M., le Havre.
Auxiliary Switchgear	Ateliers de Constructions Electriques de Delle, Villeurbanne sur Saône.
90 kV Cables	Câbles de Lyon, Lyon.
Circuit Breakers	Ateliers de Constructions Electriques de Delle, Villeurbanne sur Saône.
Isolators	E.G.I.C., Villeurbanne.

Acknowledgments

We are greatly indebted to Electricité de France for their courtesy in allowing us to visit the Argentat station and in placing at our disposal all the needful information and illustrations for the publication of this article. At Argentat we received the utmost assistance from Monsieur Capitaine, Chief of the Argentat District of EDF, and from Monsieur Fontan, the Resident Engineer. We also obtained much useful information about the design of the bulb set during a visit we paid to Ets. Neyrpic at Grenoble.

Channel Cable. Work is expected to begin this year on the power cable across the English Channel, and should be completed by 1960. The cable will operate on direct current, and will transmit 150 MW at 200 kV.

The IAHR Congress

A commentary on the Seventh Congress of the International Association for Hydraulic Research held in Lisbon in July

PART ONE

As intimated in our September issue, the International Association for Hydraulic Research held its Seventh Congress last July at the Laboratório Nacional de Engenharia Civil, Lisbon, under the Presidency of Mons. Pierre Danel. Over 80 papers were presented under four headings: Scale Effect; Cavitation; Hydraulics of Intake Works for Power Stations and of Tunnel and Channel Outlets; and Free Subjects. In view of the large number of papers presented and of the deeply mathematical nature of many of them, any attempt to furnish a comprehensive summary within our limits of space would be impossible, and we must content ourselves with a general commentary.

Nevertheless, it is possible to crystallise what appears to us to have been the fundamental issue of the Congress, which was the type of similitude to be adopted in model studies, particularly with regard to the cavitation testing of hydraulic machinery. From this standpoint the sections "Scale Effect" and "Cavitation" were interrelated, and although supported by comparatively few papers, were the really significant contribution to the proceedings. The other sections had the lion's share of the papers, some of which were of more than ordinary interest, but in our view they were not, on the whole, an examination of the frontiers of knowledge. We shall therefore make no further apology for dealing more fundamentally with this question of scaling than will be the case when we come to consider "Intake Works" and "Free Subjects."

Cavitation Scale Effects in Model Testing of Hydraulic Machines

Despite modern research the processes that cause cavities to form in the flow and give rise to undesirable effects on turbine characteristics are imperfectly understood, and there have been suggestions that model tests should be associated with Froude similitude as well as the Thoma criterion and perhaps Reynolds number. At present it is possible to reproduce characteristic changes when cavitation is sufficiently developed, but the limiting conditions that produce unfavourable influences cannot be accurately defined, although it is clear that cavitation exists before machine performance is affected. Although designers endeavour to prevent the appearance of cavitation, it must be tolerated under certain transient conditions, runaway and partial-load operation.

These fundamental aspects of cavitation scale effects were the theme of one paper from the U.S.A. and two from France along with three French papers describing test beds where these problems could be studied and perhaps resolved. The papers are noted below in order of reading for appreciation of the questions involved and of water-tunnel design for their investigation:—

Knapp (U.S.A.), "Cavitation Scale Effects."
Danel & Duport (France), "Aspects of Incipient Cavitation Similitude in Hydraulic Machines."
Wegner & Giraud (France), "Aspects of Cavitation in Hydraulic Turbines."
Berthod & Giraud (France), "Sogreah Cavitation Test Stand for Turbines and Valves."
Borguignon (France), "Hydraulic Machinery Test Stand at Chatou National Laboratory."
Hug & Jaques (France), "Output, Level and Pressure Control in Cavitation Test Installations."

These topics were of sufficient interest for a separate discussion during the Congress by engineers from France, Germany, Holland, Switzerland, Canada, U.S.A. and Great Britain under the chairmanship of Professor R. T. Knapp, of the California Institute of Technology, and a well-known authority on cavitation phenomena. Space does not permit detailed review, but the following notes outline the papers and the ideas exchanged.

Dealing with cavitation inception, Professor Knapp points out that this is influenced by three parameters: (a) the characteristics of the impurities in the liquid which form the nuclei; (b) the physical and thermodynamic properties of the liquid; (c) the hydrodynamic characteristics of the flow. The interaction of these three parameters results in a time delay in the inception of cavitation, which introduces a scale effect, and a brief analysis of the problem leads to the following tentative conclusions: (1) The same body tested at different velocities will have different values of K'_i (experimentally determined parameter for cavitation inception); (2) if similar bodies of different sizes are tested at the same velocity the smaller body will have the lower K'_i; (3) similar bodies of different sizes tested at the same value of the product (velocity × characteristic diameter or length) should have the same K'_i. In Professor Knapp's opinion there is little foundation for conclusion (3) as the validity of the underlying assumptions is open to question, and he argues that there is no justification for the conclusion that tests should be made at prototype Reynolds numbers as this would imply that the density and viscosity of the liquid affected cavitation inception, and practical evidence is against this.

The foregoing considerations apply only to cavitation inception; under conditions of partially or fully developed cavitation the author considers that model results will predict prototype performance quite accurately.

Professor Knapp returns to this question of Reynolds versus Froude scaling when considering cavitation scale effect in model studies of hydraulic

performance. Cavitation affects performance by altering the shape of the water passages, and any difference in geometric similarity in the cavitation zone between model and prototype will produce a scale effect which will become less as the physical size and the test velocity of the model are increased. This seems to point to the desirability of cavitation testing at prototype Reynolds number, but the author quotes experimental evidence to show that in the case of low Froude numbers gravity forces exert a significant influence on cavitation behaviour and that in such cases scaling should be at prototype Froude number. Indeed, Professor Knapp points out that in cavitation testing there is a scaling dilemma, for to obtain correct cavity geometry Froude number scaling is indicated, but this involves low velocities and small dimensions, in which conditions cavitation inception is delayed and cavitation zones are smaller than they should be. Fortunately, this dilemma becomes serious only in the case of low Froude numbers, and the author's general conviction is that cavitation testing should be carried out at as high a velocity as possible.

To summarise Professor Knapp's position, the scale relationships for equipment operating in the incipient and fully developed cavitation zones in terms of Froude's Law and the Thoma coefficient call for examination because of the many variables and physical phenomena involved. He maintains that because the phenomena have different characteristics one law is insufficient and consequently each phase must be analysed and appropriate scaling laws applied in association with prototype values of the Thoma cavitation parameter. Difficulties, however, arise in reproducing zonal similarity where incipient or limited cavitation tests require model velocities approaching or exceeding those in the prototype.

Danel and Duport apply these considerations to hydraulic machinery and show that for low-head turbines disregard of the elevations of different parts of the turbine can introduce errors in determining the turbine setting much in excess of those applicable to model-test measurements. They examine the validity of Froude similitude coupled with the Thoma coefficient in terms of critical values of "gaseous boiling" and vapour pressures, the former being concerned with the dissolved and non-dissolved air content and bubble nuclei and the latter with the vapour tension.

With small high-velocity models the low-pressure zone transit time is too short for gaseous boiling bubbles to appear to disturb observation or machine performance. With large models and Froude similitude the low-pressure zones are extensive and the transit times are longer, but the formation of an air-water combination makes observation difficult. Faithful reproduction of gaseous boiling demands control of the dissolved air and undissolved air nuclei, low velocities and heads that have no relationship with prototype Froude similitude.

The critical vapour pressure depends on the vapour tension, temperature and gas nuclei in the water, and vapour bubble evolution is not rapid enough to be influenced by the transit time at the usual laboratory velocities provided the air content can maintain sufficient nuclei to ensure that the critical vapour pressure and tension are the same. Simulation demands certain precautions if Froude similitude leads to reduction of the dissolved air tension and elimination of gaseous nuclei. On closed test circuits with free surfaces, investigations are planned with air injection through the resorber to verify the critical pressure and vapour tension relationship since insufficient dissolved air retards cavitation appearance and excess permits air bubble formation, which affects flow observations and machine performance.

Danel and Duport classify cavitation under two major headings, namely:—

1. Appearance of First Vapour Bubbles. With prototype velocities the life of the bubbles for expansion and resorption is much shorter than in reality, and this suggests an examination of the influence of gradual velocity reduction and longitudinal pressure gradients to determine whether there is a lower threshold transit time for the scale model.

2. Developed Cavitation in different forms accompanying progressive pressure reduction:—

(i) *Intense Bubble Emission* in the mass of moving water. If the transit time is sufficient, the bubbles collapse where the local pressure is equal to the critical pressure. Froude similitude should disclose the bubble path between formation and collapse but may introduce distortion of the bubble dimensions, from which it is concluded that it is desirable to use: (a) Prototype velocities for bubble dimension analysis, (b) Froude similitude for definition of the bubble formation and collapse zones.

(ii) *Cavitation Attached to the Surface*. This form is initially unstable and subject to rapid cyclic formation and detachment needing prototype velocities for simulation.

(iii) *Established Cavitation* where the bubbles become larger and are partially filled with vapour. The cavity dimensions are related to the surface pressure gradients and consequently the variable hydrostatic pressures should be correctly represented on the model by Froude similitude especially if the cavity extends into the downstream zone.

The effects of cavitation on output, discharge and efficiency as shown by the break in the associated sigma curves do not necessarily occur at the same point, because undesirable phenomena may appear before performance is affected and consequently definition of the limiting conditions appear to require correlation with cavity dimensions in terms of Froude similitude.

Both papers refer to vibration, noise and erosion arising from cavitation and emphasise the difficulties of reproducing such phenomena on scale models since:—

(i) Vibration and noise introduce the physical properties of water, hydraulic phenomena and mechanical construction of the turbine apart from prototype and structural similitude which obey different incompatible laws. The best that can be done is to observe periodic pressure fluctuations at different points in the machine.

(ii) The laws of erosion similitude, even if determined for simple shapes with prototype velocities, could not necessarily be extended to the turbine model. Reproduction of erosion would take too long and interpretation would be too difficult in the present state of metallurgical knowledge. A large model at prototype Froude number, however, could predict the zones exposed to erosion where highly resistant

material should be used. When coupled with a study of vapour-bubble behaviour it might indicate where improvement is desirable and perhaps define intensity but not the severity of erosion damage.

Recognition of these limitations make Wegner & Giraud's paper important because it attempts to correlate laboratory observations with those which might be expected on the prototype by classifying the appearance and location of various types of cavitation observed on models with different turbine types and operating conditions.

The customary unit head/quantity topographical diagrams defining turbine performance are used in conjunction with incipient and critical sigma curves for the first visible signs of cavitation and where there is a change of performance respectively. This demands complete similitude in terms of geometry, Froude and Thoma laws.

The good correlation that apparently exists between the various zones on this diagram and types and location of cavitation is excellently shown by photographs and curves for high-head Francis and Kaplan turbines. Some measure of success has also been obtained with actual machines, but data available for correlation in this respect are naturally extremely limited.

The remaining three papers concern the test beds installed by Sogreah and EDF to investigate hydraulic machinery cavitation by aural and stroboscopic visual observations, high-speed photography and measurement of the appropriate variables.

Berthod & Giraud describe Sogreah's cavitation test stands for vertical and horizontal Kaplan and Francis runners up to 600 mm. in diameter, and gates and valves where both Froude and Thoma similitude can be maintained simultaneously over wide discharge, head and power ranges with simulation of upstream and downstream free-surface water levels.

The paper details the closed-circuit water tunnel with pumps, electrical dynamometers, air resorbers, and the controls associated with speed, air pressure, dissolved air and water temperature and upstream and downstream levels as well as flow, head and output measurements. The equipment includes:—

(i) Means of releasing air bubbles and emulsions by providing free surfaces under controlled atmospheric conditions and suitably dimensioned resorbers to reduce dissolved air, air nuclei and gaseous boiling without delaying vaporisation.

(ii) Visual observation facilities and responsive measuring equipment for investigating the influence of air-and-water mixtures and air injection in conformity with prototype conditions on performance.

These are important improvements in model tests not hitherto possible because: (a) A known field remedy for cavitation at partial loads is to admit air by trial-and-error methods, (b) tubular pump turbines for tidal stations are subject to continuously varying upstream and downstream levels.

Bourguignon's paper is a valuable companion and covers the hydraulic machinery test station at Chatou in the design of which Sogreah participated. It elaborates some of the detailed aspects of water-tunnel design, equipment and control for a maximum runner diameter of 700 mm. and heads up to 20 m. The problems to be investigated are similar, with the added indication that, because there may be a turbulent threshold limitation below which model-prototype flow may not be similar, studies will be made to ascertain whether there is a critical relationship between Reynolds number, the model diameter and machine characteristics.

Hug and Jaques' contribution amplifies these two papers by detailing various methods of control and their application to water tunnels generally and those at Sogreah and Chatou in particular.

Other Scale-Effect and Cavitation Papers

Apart from Professor Knapp's paper, the section on "Scale Effect" contained only seven papers, of which the majority were concerned explicitly or implicitly with estuary and maritime models. The problem of Reynolds versus Froude scaling, however, is discussed in a paper "Sur l'Effet d'Echelle dans les modèles Hydrauliques" by G. Supino, of Bologna University. The author points out that scale effect in hydraulic models arises from the impossibility of reproducing in one model the same Froude and Reynolds numbers as the prototype, and refers to the suggestion that a series of models should be constructed at different scales, all having the prototype Froude number but with Reynolds number increasing with the scale. Such a procedure is seldom practicable on account of the space limitations in the average laboratory, but it is possible to achieve a similar result by retaining a fixed horizontal scale and varying the vertical scale, as it can be shown that the Reynolds number is influenced mainly by the vertical scale. In certain cases it is possible to obtain results from a single model by using different depths of water.

A record of practical experience in taking scale effects into account is contained in a paper "Scale Effect in Hydraulic Research" by D. V. Joglekar, C. V. Gole and S. V. Chitale. This paper refers to a variety of model tests carried out at the Central Water Power Research Station, Poona, in which scale effects were involved, and includes both geometrically similar and vertically distorted models.

A paper by Charles W. Thomas, of the U.S. Bureau of Reclamation, gives an interesting account of comparative tests that were carried out on three models, built to different scales, of the Grand Coulee dam spillway. A 1:40 model, representing approximately one gate length of spillway, was first constructed to study the behaviour of the energy dissipator, and as certain difficulties were encountered in the pressure studies a 1:15 model was built. Later, a 1:120 model of the entire spillway, power houses and a downstream reach of the river was built to study the general hydraulics of the structure and the adjacent river channel. The existence of these models gave rise to the idea of using them for comparative studies, and after the individual studies with each model had been completed, the models were modified to bring them into as close agreement as possible before the comparative studies were initiated. Tests were then conducted on velocities, pressures and scour.

Velocities on the face of the dam revealed close agreement between all three models and the prototype, and it did not appear that a limiting factor on the size of the model was reached. In the dissipator, on the other hand, more complete velocity observations were obtainable from the larger models.

Pressure measurements were considered impracticable on the smallest model, but the results obtained

from the two larger models again revealed close agreement.

The scour studies showed that side-wall effects were significant, particularly in the case of the smallest model, which developed considerably more scour than the larger models. Further, the basic assumptions made in regard to scale relationships of the mean grain size were not borne out by the observations, although the data were not adequate to generalise the results or establish corrections.

In the "Cavitation" section three papers, which are not related to the question of scale effect, remain to be mentioned. In a paper "Cavitation Effects in Unsteady Two and Three-Dimensional Flows," S. F. Borg and P. N. Hu, of Stevens Institute of Technology, Hoboken, present some of the results of a study of the wedge water entry problem based upon a new formulation of the basic equations of hydrodynamics applicable to this problem. The paper includes: (a) a development of the equations and the various relations and properties which follow from these; (b) an exact relaxation solution for an unsymmetrical wedge; (c) an experimental check on the free streamline shape of case (b); and (d) approximate solutions for blunt-nosed bodies, both two-dimensional and three-dimensional, symmetrical and unsymmetrical. In cases (b) and (d) the exact and approximate solutions indicate regions of negative pressure, corresponding to cavitation or separation regions in a real fluid.

Indian practice in the design of sluices to secure cavitation-free operation is outlined in a paper by D. V. Joglekar and P. M. Damle, of the Central Water Power Research Station, Poona. Design procedure is standardised to some extent, but model tests are used to check and modify the design of important structures. This is illustrated by reference to the model tests on the sluices for Gandi Sagar and Hirakud dams.

Siphon spillways are much favoured in India, and a paper by M. Maitra, of the River Research Institute, West Bengal, gives an indication of the method of computing an economic profile for a siphon spillway, from the point of view of cavitation, so that the maximum coefficient of discharge can be realised under a given operating head or with a dimension of siphon which characterises its size.

(To be continued)

Symposium on Underground Stations

AT the annual meeting of the American Society of Civil Engineers, to be held in New York in October, the Power Division will devote its sessions mainly to a symposium on underground hydro-electric plants, under the presidency of Mr. R. A. Sutherland. Papers will be read representative of practice in this field in many parts of the world, the programme being as follows: *October 15*—"Underground Plants in Sweden," K. V. T. Nilsson, MASCE, Civil Engineering Director, Swedish State Power Board; "Underground Power Plants," Adolph J. Ackerman, MASCE, Consulting Engineer, Madison, Wisconsin. *October 17*—"Underground Power Plants in Italy, with special reference to A.A.D.E. and Montecatini Power Stations," Dr. Ing. Carlo Semenza, MASCE, Chief Engineer, Hydraulic Construction Department, S.A.D.E., Venice, and Dr. Ing. Dante Finzi, Chief Engineer, Hydro-electric Construction Department, Montecatini, Milan; "The Haas Underground Power Plant," J. Barry Cooke, AMASCE, Senior Civil Engineer, Pacific Gas & Electric Company; "Underground Power Plants in Yugoslavia," Dr. V. Yevdjevic, MASCE, Director, Institute of Hydraulic Engineering, Yugoslavia; "Underground Power Plants of the Edison Company, Milan, Italy," Dr. Claudio Marcello, MASCE, Consulting Engineer & Technical Director, The Edison Company; "Underground Power Plants in Canada," A. W. F. McQueen, MASCE, President, H.G. Acres Company; "The T1 Underground Power Station of the Snowy Mountains Hydro-electric Authority, Australia," T. A. Lang, ASASCE, Associate Commissioner. *October 18*—"Ambuklao Underground Power Station," A. Eberhardt, AMASCE, Head Civil Engineer, Harza Engineering Company; "Montgomery Dam, Colorado, Rockfill with Asphaltic Concrete Deck," F. W. Scheidenhelm, MASCE, Consulting Engineer, J. B. Snethlage, MASCE, Consulting Engineer, and A. M. Vanderlip, MASCE, Associate Engineer; "The Sudagai Underground Power Plant, Japan," S. Mimura, Civil Engineer, Tokyo Electric Power Company. It is hoped that papers will also be available on "Underground Plants in Switzerland," by Dr. A. Kaech, Consulting Engineer, Lucerne, and on "The Ceannacroc and Glen Moriston Underground Power Plants in Scotland," by C. M. Roberts, MICE, partner of Sir William Halcrow & Partners.

In preparation for this symposium a "Bibliography, Underground Hydro-electric Power Plants" has been published as a Proceeding Separate of the ASCE. It has been prepared by J. Barry Cooke, AMASCE, and Arthur G. Strassburger, JMASCE, respectively Senior Civil Engineer and Engineering Designer of Pacific Gas and Electric Company, San Francisco, and in addition to the bibliography contains a list of the world's underground stations in operation, under construction, and projected. This list contains upwards of 300 entries.

A Portuguese Consulting Organisation

A Portuguese consulting organisation has recently been set up under the title of Hidrotecnica Portuguesa, Lda., Avenida do Aeroporto 102, Lisbon, specialising in civil engineering, hydrology, hydraulics, and the design of hydraulic structures, dams, and power plants. The director is Prof. A. Abcasis Manzanares and the partners are Eng. J. Laginha Serafim, Eng. Feranando Abcasis, Eng. A. F. de Silveira and Eng. J. Amorim Ferreira.

Investigations are in hand for schemes in Portugal, Brazil, Mozambique, Angola, and Guinea. Although the organisation is naturally largely interested in developments in Portugal and in Portuguese overseas territories, it is also available for investigations in other parts of the world.

Cavitation in Turbomachines

In this section the effect of cavitation on turbomachine design is considered, and the conditions of cavitation similitude in model testing are discussed

By F. A. L. WINTERNITZ, Dipl. Ing. E.T.H., V.D.I.*

PART TWO

Cavitation and Turbomachine Design

The occurrence of cavitation in turbomachines is design conditioned, and it is by suitable design measures that improvements may be realised. Both cavitation form and related effects are controlled by passage-of-flow detail. This follows from equations (4) and (4a) and from equation (9), and is equally true for clearance and roughness cavitation.

The consequences of cavitation: (1) Loss of performance; (2) material damage; (3) vibration; and (4) noise; are briefly discussed in the following. They are controlled by combinations of factors so complex that theoretical treatment is ruled out, which has given the individual model test its outstanding importance.

(1) *Effect on Performance.* The effect of cavitation on performance is to a certain extent influenced by machine specific speed. Efficiency breaks down more rapidly in low-specific-speed machines with narrow passages, than in those of the axial-flow type with few and widely spaced runner blades. The results from venturi tests and flat-plate analogy may illustrate what happens. The efficiency of the diffuser part in a small venturi test section was used as a criterion for cavitation[36], the results in Fig. 6*a* being similar to those sometimes obtained from small low-specific-speed pumps. For medium air content, cavitation at high absolute pressures brought an initial increase in velocity before efficiency fell off. The sharp break in the efficiency curve at low pressure indicates that the whole width of the test section was instantaneously affected by cavitation.

The sudden breakdown in the performance of low-specific-speed machines may thus be ascribed to the mean runner passage pressure being rapidly reduced locally to vapour pressure. In axial-flow machines of high specific speed, effects are far more gradual, since in general, runner passages are replaced by "lifting surfaces" moving through a free stream. Cavitation must reduce the lift and increase the drag exerted by the blades to affect performance. Flat-plate analogy may serve to demonstrate this. For small angles of incidence and small cavitation indices, with cavitation extending from the leading edge, Betz derived expressions for the lift and drag of a flat plate:

$$\left.\begin{aligned} C_L &= \frac{\pi}{2}\cdot\alpha+\sigma \\ C_D &= C_L\cdot\alpha \end{aligned}\right\} \qquad \ldots (14)$$

where C_L, C_D = lift and drag coefficients, α = angle of incidence.

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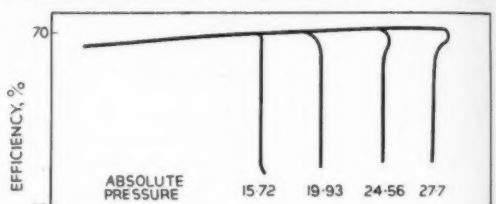
The flow is in contact with the pressure face only and the contour on the suction side is without effect. This justifies comparison with hydrofoil performance, and the agreement established in Walchner's tests[37] was good. The expression for C_L, equation (14), has been combined in Fig. 6 with

$$C_L = 1{\cdot}71\ \pi\ (\alpha + 1{\cdot}67\ f/e) \qquad \ldots (15)$$

the lift coefficient of a moderately cambered circular arc section to illustrate the effect of cavitation on lift coefficient[38]. Fig. 7*a* demonstrates that reasonable agreement may also be obtained for cascade lift results, which allow for mutual blade interference and resemble the case of the axial flow machine more closely than the isolated hydrofoil. For $\alpha = 3$ degrees



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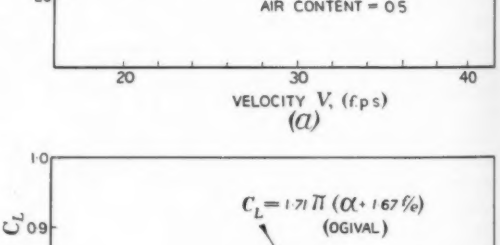


(*b*)

Fig. 6. Effect of cavitation on (a) the efficiency of the diffuser of a small venturi test section, and on (b) the lift coefficient by flat-plate analogy

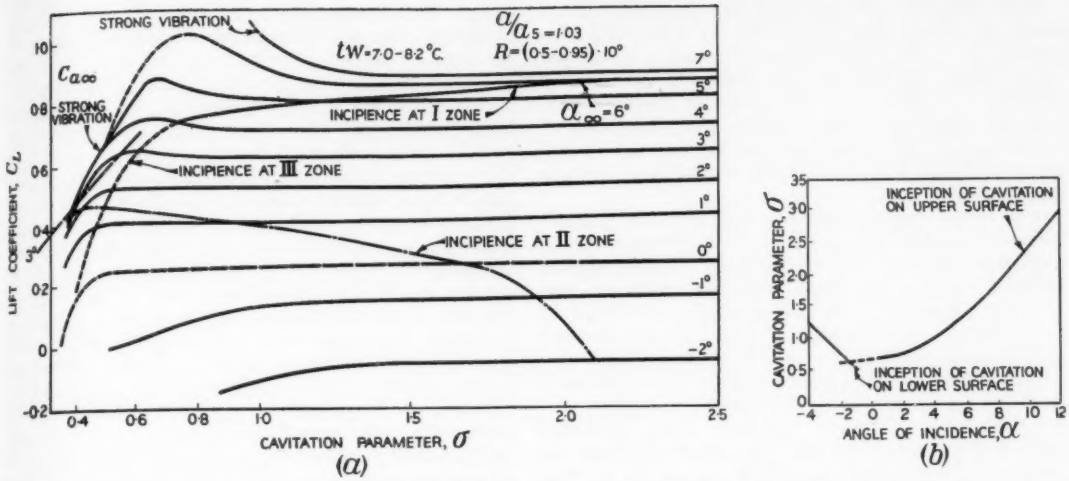


Fig. 7. (a) Cascade test results and flat-plate analogy for $\alpha=3°$; (b) Cavitation inception as a fraction of angle of incidence for N.A.C.A. 4412

the lift coefficient as a function of σ was plotted into results obtained by Numachi and collaborators[39] for hydrofoil N.A.S. 13368, eight per cent. thickness ratio, staggered with a cascade angle $\theta=25{\cdot}73$ and $s/l=1{\cdot}237$.

By analogy, therefore, cavitation affects the performance of low-specific-speed machines by blockage of the runner passage and by blade contour modifications in axial-flow machines. Both effects depend on location and extent of the cavitation zone, which in turn is controlled by design features and operating conditions. Fig. 7*b* demonstrates this dependence for an isolated hydrofoil, NACA 4412. The results were taken from Ref. 40.

In agreement with similar cascade performance, cavitation on the suction face was concentrated near the leading edge for large angles of incidence. For small positive α values this extended over the blade suction side to shift to the pressure face for negative angles of incidence. The extent of the cavitation zone is controlled by the absolute pressure available for bubble collapse, as pointed out before.

Fig. 7*b* indicates that in machines with fixed-blade runners the dependence of the location of the cavitation zone on the angle of attack is one which varies with load. This is borne out by experiment[41].

In designing for optimum cavitation conditions with regard to performance it is essential to avoid sudden contour changes in guide surfaces upstream of the runner[42], and in the runner casing[33], since separation or eddy formation are conducive to the development of cavitation.

The lowest pressures in a turbomachine occur in the runner, which transmits the torque generated or absorbed. The runner design is therefore crucial for ultimate cavitation performance of the machine; the formation of the leading edge and the pressure distribution over the suction face are decisive factors in this.

Leading-edge contour affects the magnitude of the suction pressure peak which is a consequence of the flow displacement due to the blade. Reduced to a minimum by correct design, substantial improvements may result[43]. In axial flow machines the blade leading edges generally approximate to an elliptical shape, in agreement with experimental results[44] which for zero angle of incidence showed a very favourable pressure distribution for the elongated ellipse.

The pressure distribution on the blade suction side is of essential importance to cavitation behaviour. This is easily realised by the example of the axial-flow runner. If pressure distribution is assumed roughly triangular in shape, for instance, the suction peak value follows from:

$$\Delta H_{\min.}\approx kC_L\frac{W^2_{\infty}}{g} \qquad \ldots (16)$$

where k defines the contribution of the suction pressure to the total lift. From Ref. 21 $k_P\sim0{\cdot}7$ for pumps and $k_T\sim0{\cdot}3$ for turbines.

If one now prescribes an elliptical pressure distribution over the blade suction face:

$$\Delta H_{\min.}\approx\frac{2}{\pi}kC_L\frac{W^2_{\infty}}{g} \qquad \ldots (16a)$$

and thus for a pump $\frac{2}{\pi}k_P\simeq0{\cdot}45$. For blade sections with near-elliptical suction pressure distribution $k_P\approx0{\cdot}55$, so that $\frac{2}{\pi}k_P$ reduces to$\sim0{\cdot}35$.

The improvement of runner cavitation characteristics by suitable blade design is dictated by the trend of modern development. If equation (16) is introduced in equation (6a):

$$\Delta H_T\simeq\frac{p_v}{\gamma}+\lambda_1\frac{C^2_2}{2g}+k_TC_L\frac{W^2_{\infty}}{g} \qquad \ldots (17)$$

The force per unit mass acting peripherally on the blade is:

$$P^*_U=C_{U_1}-C_{U_2}\simeq\tfrac{1}{2}C_L\frac{l}{s}W_{\infty} \qquad \ldots (18)$$

where C_{U_1}, C_{U_2}=peripheral components of absolute velocities.

And so: $$\Delta H_T\simeq\frac{p_v}{\gamma}+\lambda_1\frac{C^2_2}{2g}+2\,k_TP^*_U\frac{sW_{\infty}}{l\,g} \qquad \ldots (19)$$

From equation (19) it follows that the modern tendency to reduce weight and size by increasing P^*_v and W_∞, must for a set value of s/l enhance the danger of cavitation This has led to the runner of high solidity through reduction of s/l. The effect of increased friction loss must be weighed against the advantages of improved cavitation performance. The increased interference effects between blades necessitates cascade treatment.

The improvement of the blading cavitation characteristics is in the foreground of development work on axial-flow machines of high efficiency. The use of thin aerofoil sections from high speed aerodynamics has been investigated[45]. The flat pressure distribution of this type at correct angle of attack may effect the improvement outlined by use of equation (16a). Experience with propeller pumps designed on these lines confirms the suspected sensitivity of such blade sections to angle of attack variation. More than one head-flow characteristic has been found to exist for nominally identical test conditions, indicating possible effects of turbulence on the blade pressure distribution.

The modern method of design is to calculate cascade arrangements of blades for specified pressure distributions, and to verify results in the experiment. Methods of calculation are available and systematic investigations are in progress[39].

In axial-flow runners sections endangered by cavitation may be relieved through suitable choice of blade circulation. Briefly, the general practice is to reduce the circulation at the tip and near the hub, to decrease the lift coefficient from hub to tip while increasing the chord length, and to taper blade thickness from hub to tip.

An entirely different and rather daring approach to the problem of cavitation and turbomachine design has been proposed by Wislicenus[19] for centrifugal and axial-flow pumps, who suggests operation under conditions of fully developed cavitation. Then λ_2, λ^*_2 in equations (6a) and (6b) are zero, and low values of the ratio of the axial to the peripheral velocity result in a substantial increase in suction specific speed, values in excess of 60,000 (ft., gal. per min. units) being considered. The increase in absolute speed of rotation, which thereby becomes possible, would be of the order of two to six times that attainable under the existing empirical limitations. Such a mode of operation would impart only kinetic energy to the liquid; it is the efficient conversion of this energy into pressure, under the three-dimensional flow aspects encountered in hydraulic turbomachines, which is the as yet unsolved problem in the way of realising such a proposal. If, as tentatively suggested, efficiencies of 70 to 80% could be obtained by this mode of operation, a very considerable advance would indeed have been effected in the design of such turbomachines. The problem of cavitation damage may not arise, the case being similar to the previously mentioned example of the condensate extraction pump, but it is at least feasible that severe vibrations might limit the useful range of axial-flow pumps when operated with supercavitating impeller blades.

(2) *Material Damage*. Cavitation pitting has been observed on guide and speed vanes, at the tongue of spiral casings, in runners and in the throat and on splitters of draft tubes. Of particular importance are all forms of damage which have been found to occur while machine efficiency is still unaffected by cavitation. Possible causes are contour separation, roughness and clearance flow.

Flow separation due to wall curvature and negative pressure gradients can give rise to cavitation in zones of low absolute pressure. Correct passage contours may be developed in aerodynamic tests by means of flow and wall-pressure surveys.

Roughness cavitation may be localised, on indi-

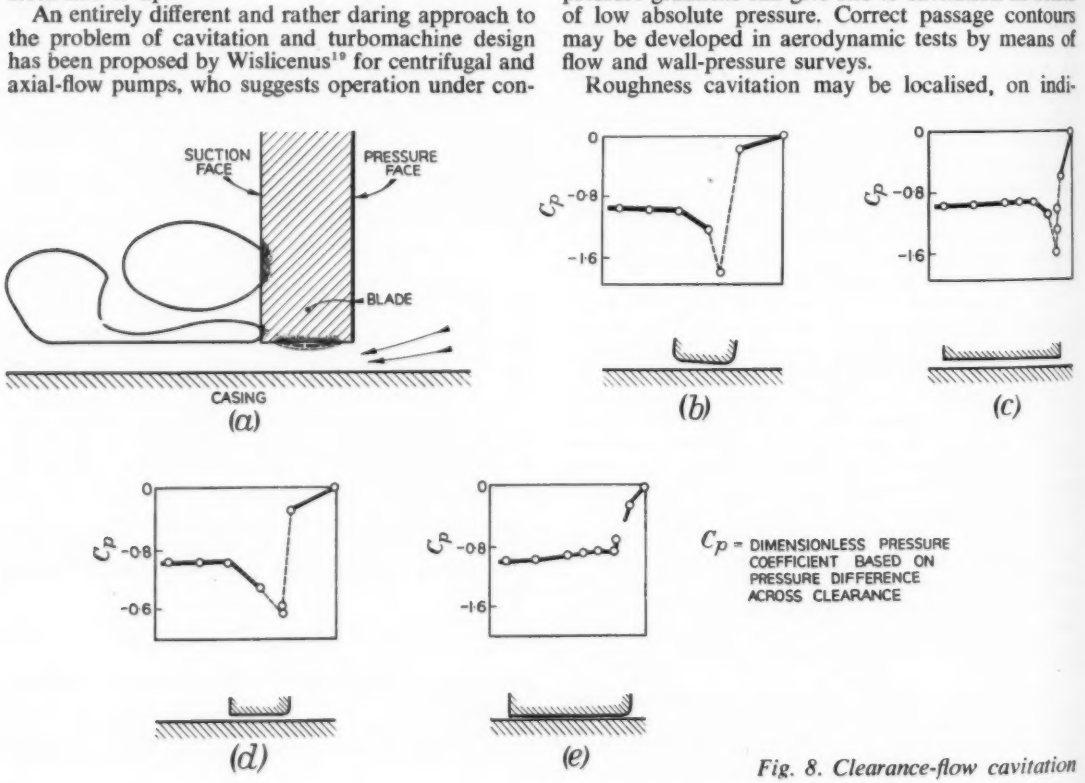


Fig. 8. Clearance-flow cavitation

vidual obstacles, or of the strip or belt type. The remedy lies in adequate surface finish[35].

Clearance flow in axial-flow machines can be the cause of severe pitting at the blade tip and on the suction face in the tip region, as well as on the runner casing. Fig. 8*a* shows the type of vortex formation which originates from the tip clearance and is controlled by the edge contours of the runner tip section, clearance width and the available pressure difference.

Attempts at blade protection by means of shroud strips[46] have been abandoned, probably due to detrimental effect on efficiency. Shal'nev[34] investigated two-dimensional tip-clearance arrangements, Figs. 8*b* to *e*, from which *e* was chosen for the modification of a Kaplan turbine with severe pitting damage on blades and casing[33]. The output of the unit was 1,400 kW, metric specific speed 730, runner diameter 3,000 mm. The radius on the pressure edge was chosen one half of the respective blade thickness and great care was taken to avoid a clearance of diffuser shape. After the modification, the damage did not recur. No check was carried out on the effect of the modification on turbine efficiency, which is reasoned to be small. Tip-clearance formations of diffuser shape were found conducive to the separation type of cavitation.

(3) *Vibration.* Vibration may be due to blade excitation or runner-hub cavitation and may cause load instability in turbine units. Draft tube surge is considered the consequence of hub vortex cavitation. In cascade tests, blade excitation is linked to supercavitation on the suction side, extending beyond chord length[39]. Under these conditions, lift and drag coefficient are already seriously affected.

Measures available to deal with serious vibration due to cavitation are alleviating rather than corrective. Trailing-edge modifications have brought improvement. More often one resorts to injection of compressed air which acts as a shock absorber[47]. This is an emergency measure only since the admission of air may appreciably lower the machine efficiency. Lastly the output may need to be restricted.

(4) *Noise.* Objectionable cavitation noise is in general related to fairly developed stages of cavitation, the cause itself therefore demanding attention.

Cavitation noise, as vibration, may be suppressed by air admission which again can only be an emergency measure.

Model Testing and the Conditions of Cavitation Similitude

The complexity of the cavitation problem rules out theoretical solutions. Model tests have become the indispensable tool of research and engineering development work. The use of models in fluid-flow investigations requires the knowledge and consequential application of the laws of similitude. The fact that, in general, similitude can only be approximate in conjunction with observed discrepancies between model-test results and field experience, has of late thrown some doubt on the validity of the methods employed in such experiments. A critical analysis of the possible scale effects is, therefore, of importance.

Ideally, complete geometric, kinematic and dynamic similarity is required. For turbomachines, the geometric similarity does not generally extend to roughness and clearance formation, and for this reason alone no agreement must be expected for these forms

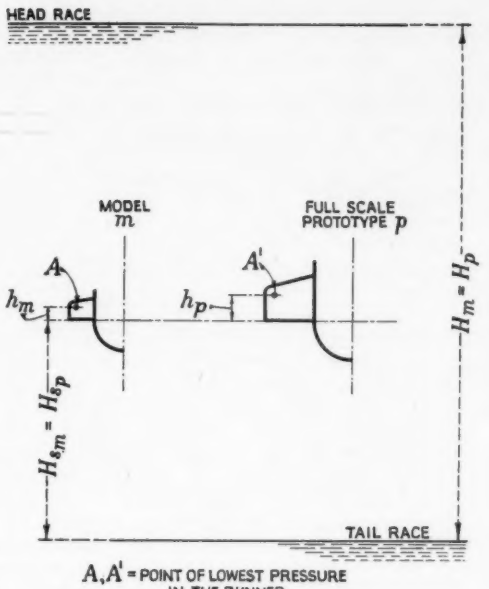


Fig. 9. Froude number scale effect

of cavitation between model and full-scale machine.

Geometric similarity leads to the requirement:

$$N_s = \text{constant} \qquad \ldots (20)$$

The kinematic condition of similarity:

$$\frac{Q}{ND^3} = \text{constant} \qquad \ldots (21)$$

where D = runner diameter, is fulfilled in the identity of such coefficients as ϕ or K_u, where:

$$\phi = \frac{C_m}{U}, \quad K_u = \frac{U}{\sqrt{2gH_{T,P}}} \qquad \ldots (22)$$

C_m = axial component of C, U = peripheral velocity.

The similitude of forces, however, can only be approximate. From the dimensionless equations of motion, it follows that Reynolds number, Froude number and the pressure coefficient must be the same for model and full-scale machine. If one includes Weber number, and identifies the pressure coefficient with K or σ:

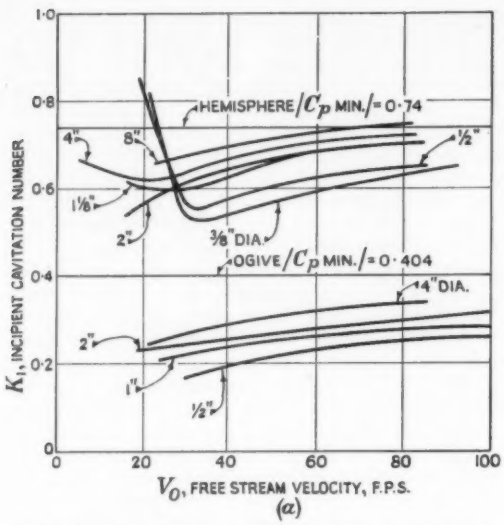
$$K, \sigma = f(Re, F, We, \text{test geometry}) \qquad \ldots (23)$$

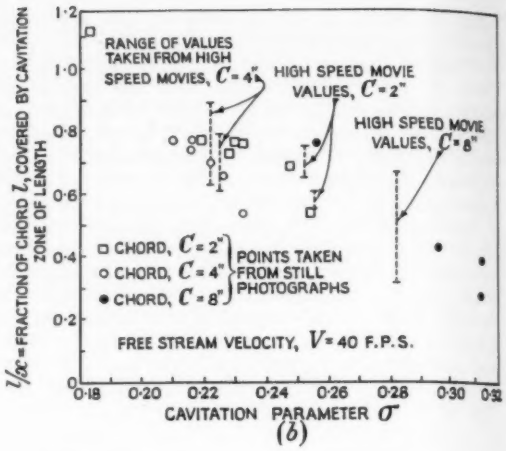
where test geometry extends to roughness and clearance parameters.

Reynolds number effects are assumed insignificant if tests are carried out above the critical range of transition; for axial-flow machines this is, in general, assumed as $Re > 2$ to 4×10^5 if based on blade chord. The Reynolds condition can rarely be fulfilled. For instance, the choice of a model-runner diameter of 1/3·16 of full size, and a plant head of 30 ft. could result in the requirement of 300 ft. test head.

Froude number has always been considered an essential parameter since gravity forces are the only external forces acting. This leads to:

$$\sigma = \text{constant}, \quad F = \text{constant} \qquad \ldots (24)$$




RANGE OF VALUES TAKEN FROM HIGH SPEED MOVIES, C = 4"
HIGH SPEED MOVIE VALUES, C = 2"
HIGH SPEED MOVIE VALUES, C = 8"
CHORD, C = 2"
CHORD, C = 4"
CHORD, C = 8"
POINTS TAKEN FROM STILL PHOTOGRAPHS
FREE STREAM VELOCITY, V = 40 F.P.S.
l/c = FRACTION OF CHORD L, COVERED BY CAVITATION ZONE OF LENGTH
CAVITATION PARAMETER σ
(b)

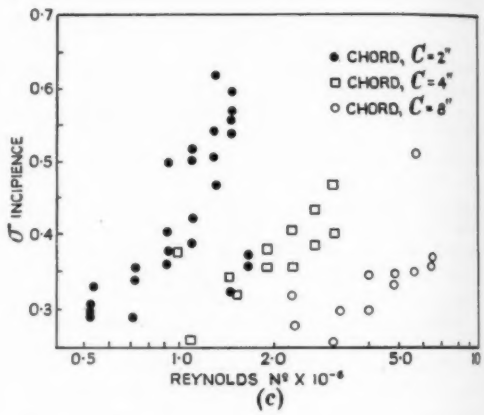


Fig. 10. Scale effects: (a) Cavitation scale effect on axi-symmetric bodies; (b) non-similarity of cavitation zone on similar Joukowski hydrofoils; (c) speed and size scale effects on similar Joukowski hydrofoils

as the condition of similarity. Gerber[48] outlined the extreme experimental difficulties in the way of realising the Froude condition. An argument against unqualified adherence to Froude is that such effects should only become significant in those cases where the gravity-force differences between model and full-scale machine are appreciable by comparison with the inertia forces. Fig. 9 demonstrates this in the case of a turbomachine model tested under the actual head. Froude number effects will be insignificant for medium and high-head machines. For low-head machines, model results would be too favourable, but the possible discrepancy is minimised in practice by reference to the blade centreline, Fig. 4*a*, in determining H_s.

Outright objections to using Froude similarity are low outputs at the brake and thus increased accuracy requirements, and the possibility of boundary-layer transition due to the low velocities either in the step from model to full-scale machine or even in the model runner between hub and tip blade sections. Since the head across the turbine model is reduced in the ratio of the diameter of the model to that of the full-scale runner, the low rig pressures required to obtain the relevant $\sigma_{crit.}$ values may precipitate the release of air out of solution, with possible detrimental effects on experimental accuracy. The importance attached to the study of Froude effects lead to the construction of cavitation test rigs with runner diameters between 400 and 600 mm. (∼15·5 to ∼23·5 in.). In addition, some of these have design features assuring reabsorption of the air that has come out of solution in the low-pressure zone.

Weber number effects were recently investigated[7] by adding a wetting agent to the water in a cavitation tunnel. No significant effects on cavitation pressure resulted.

On this basis, and provided that K or σ are significant parameters unaffected by absolute pressure, velocity or size, theoretically no significant scale effects should occur in model tests on medium and high-head water turbines and pumps. The adequate conditions of dynamic similarity are then:

$$\sigma = \text{constant}, \quad \frac{H_{T.P}}{N^2 D^2} = \text{constant}, \quad \frac{H_{T.P} \cdot D^4}{Q^2} = \text{constant} \qquad \ldots (25)$$

However, it has been shown for bodies of revolution, Ref. 3, and for Joukowski hydrofoils that both size and speed scale effects exist, Figs. 10*a*, *b* and *c*. In venturi test sections both Ziegler's[16] and tests carried out at the Mechanical Engineering Research Laboratory[36] showed speed scale effects.

There is no reason to assume that such scale effects do not occur in hydraulic turbomachines. From Fig. 10A, for instance, it would follow by analogy that neither the Froude condition nor the adherence to Reinhardt's time parameter[49]:

$$\frac{D_m}{D_p} = \frac{\sqrt{H_m}}{\sqrt{H_p}} \qquad \ldots (26)$$

m, p = suffices for model and prototype, could compensate for the recorded scale effects. These would be smallest for tests run at the same speed or, for a turbomachine, under the same head.

In Figs. 10*b* and *c* the trend of the scale effect with velocity is the same as for the axi-symmetric bodies, Fig. 10*a*, but size has an opposite effect. This may be due to the different techniques of measurement, sound

intensity in the one and analysis of single flash photographs in the other case. It should be noted that the extent of the cavitation zones on the hydrofoils is different with size for the same parameter σ.

These experimental results confirm a previous conclusion that no definite cavitation pressure exists, and that the assumption of cavitation inception commencing at vapour pressure may be invalidated by other physical aspects.

In this context, the effect of absolute head, one of the crucial problems in present-day cavitation testing on turbomachine models, must be examined. Theoretically, as has been shown, no effect should exist and the adequate conditions for geometric, kinetic and dynamic similarity should be:

$$S^* = \text{constant}, \quad \frac{C_m}{U_e} = \text{constant}, \quad 2g\frac{\Delta H}{C^2{}_m}, \quad 2g\frac{\Delta H}{U^2{}_e} = \text{constant} \qquad \ldots (27)$$

U_e = peripheral velocity in runner eye.

Experimental evidence for the effect of absolute test head on cavitation test results is insufficient and inconclusive[48]. In tests on model turbines under heads varying from 1 to 10 m. (3·3 to 37·8 ft.) Spannhake found the cavitation coefficient markedly affected. These results have never been satisfactorily corroborated under higher heads[50], probably due to the different manner in which the same σ is produced. Under a low test head low ambient rig pressures are required, and may be associated with longer time of passage of the flow through low pressure zones, and such effects as possible air release in the draft tube. Efficient shaft sealing on the model must be guaranteed.

In the face of possible scale effects and thus in view of possible errors, it must be stressed that the bulk of experience indicates good agreement between model and field results and that doubts expressed today are chiefly justified in the light of recent developments. The possible effects of test head, for instance, have gained in importance with the extension of the operating range of Kaplan turbines to heads not easily reproducible in the cavitation laboratory.

The cavitation model test is the most accurate means available for assessing the cavitation characteristics of turbomachines. Until quite recently it has been general practice to use cavitation results from tests in which the model runner and some, but not necessary all, components of the model turbine were true to scale. The tendency today favours cavitation tests on complete scale models, a practice frequently adopted in model efficiency tests[51].

Cavitation test procedure for model turbines consists of determining unit power and discharge as a function of the cavitation parameter within the range of operation, that is within the range of ϕ or K_u values. The critical conditions are determined from the break in either the unit power or discharge curve, whichever occurs at the higher σ value, and are plotted against unit discharge with absolute test head or either ϕ or K_u as parameter.

For centrifugal pumps $\sigma_{crit.}$ is found for the break in the head-capacity curve, and presented on a K_u unit discharge basis.

Other methods used in detecting and classifying cavitation in turbomachines are visual observations under stroboscopic light, and the measurement of noise, vibration and pressure[52, 53] as well as coating techniques in runner-blade investigations.

Cavitation model testing is expensive, which is one of the reasons why it has increasingly been supplemented by aerodynamic methods which also offer far greater flexibility. Flow-in-component investigations using air and the development of suitable blading for the high solidity runners of modern axial-flow machines in aerodynamic cascade tests is today industrial routine procedure. This has been extended to complete air models of hydraulic turbomachines[54] and even to the determination in such tests of the critical cavitation coefficient[55]. Aerodynamic investigations, however, are limited insofar as they cannot supply information on performance under conditions of cavitation advanced from the incipient stage, nor can they be used for reliable prediction of the onset of separation—or vortex cavitation. The critical cavitation coefficient of the air model tests will therefore be an inadequate criterion in all those cases where plant operation dictates acceptance of tolerable cavitation in the machine, or where an indication is wanted of the possible danger of pitting due to gap or clearance cavitation.

Little is known at present about scale effects in the occurrence of cavitation damage, beyond the fact that pitting occurs not infrequently in zones which on the model were cavitation-free or, conversely, that no damage occurs in sections which from model observations were considered endangered by cavitation attack. Hydrodynamic similarity with regard to cavitation therefore by no means signifies similarity of cavitation damage.

(To be continued)

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(Continued on page 389)

Original Tendencies in Power-House Design in Hydro-Electric Installations - 2

By SERGE LELIAVSKY, Ph.D., M.I.C.E. A.Am.Soc.C.E.

AS yet we might say that we have examined the recent tendencies towards improvements in power-house design from two different standpoints: (a) general convenience, and (b) stresses. There is, however, a third, and by no means less important consideration, viz: (c) the currents generated in the channel upstream and downstream of the power station. Here again, much new information and many original ideas have been forthcoming. In fact, two particularly important aspects of the problem have lately attracted much attention—the losses of energy due to excessive secondary circulation, and the erosion of the bed consequent thereupon.

Before discussing the various individual proposals which have been made it may be of advantage to consider a basic principle, which can be regarded as being applicable to all hydraulic stations built on alluvial rivers. In this connection attention is called to the concept "centre of discharge" described and explained on page 171 of the second volume of the writer's book. "Irrigation and Hydraulic Design." As

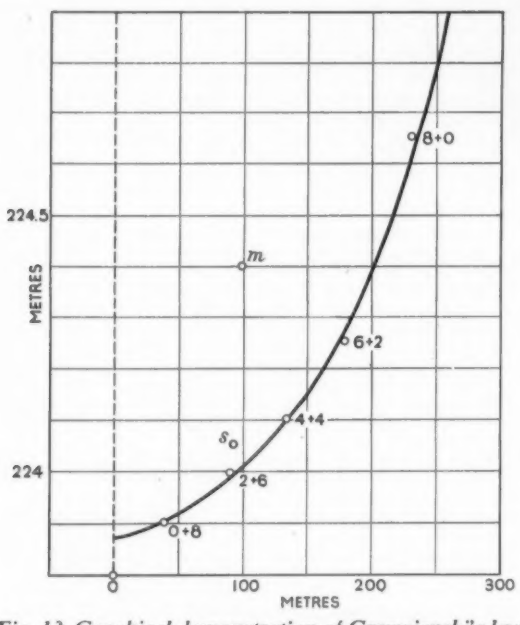


Fig. 13. Graphical demonstration of Grzywienski's law

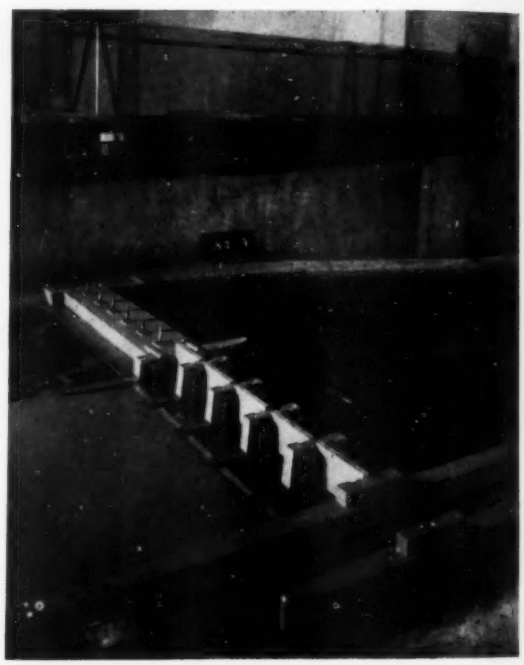


Fig. 14. One of Prof. Grzywienski's model experiments on the effect of horizontal eccentricity of station layout on flow

presented therein, the level, only, of this centre was considered to be a significant parameter. There is, however, no particular difficulty in extending the scope of this principle so as to include, also, the position of the centre of the discharge in plan. The point is of some importance because it seems that, particularly during the critical period of flood, the centre of the discharge of the original channel must coincide, in plan, with the centre of the discharge of the constricted section in the hydraulic installation. In fact, by comparing a large number of consistent model experiments, Professor A. Grzywienski concludes that *ceteris paribus* the loss of head increases as the square of the horizontal eccentricity, as measured between these two centres—especially at high discharges.[4]

[4] "Généralités sur les divers types d'usines en rivière, Les centrales submersibles," Extract from *La Houille Blanche*, No. 4, July-August 1950.

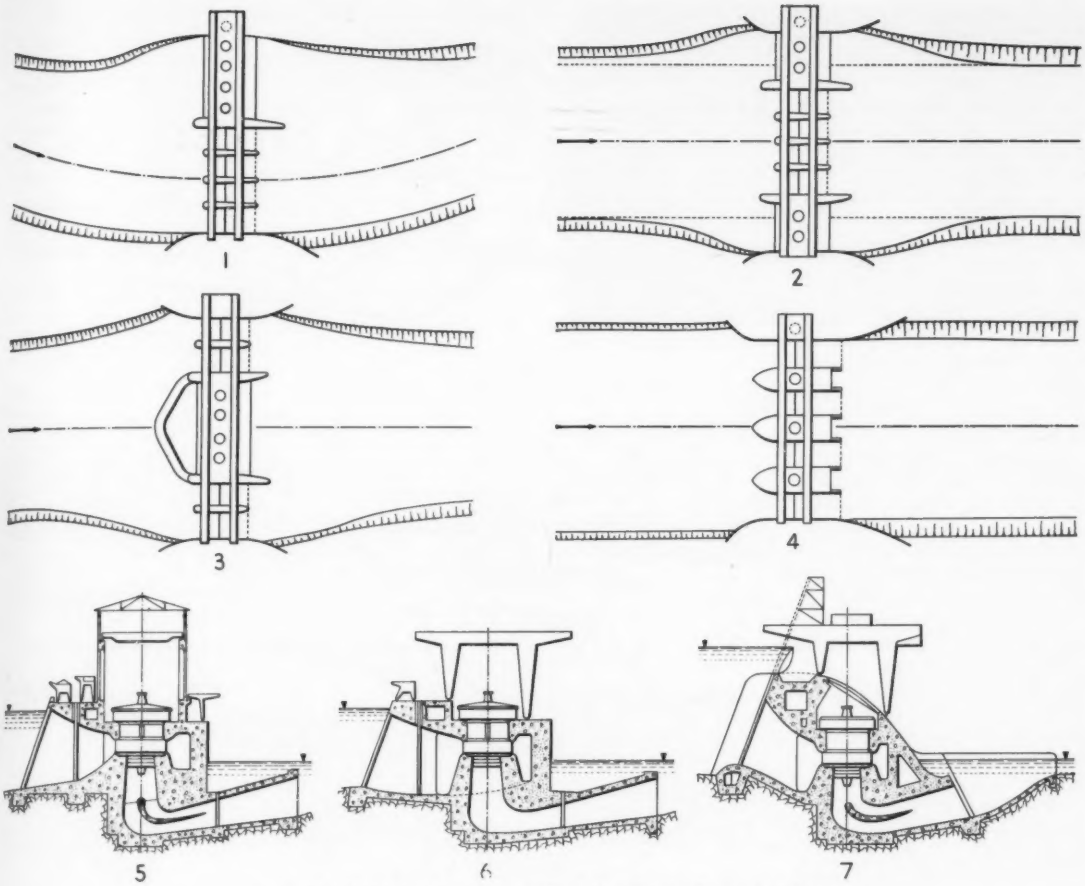


Fig. 15. Various layouts studied by Prof. Grzywienski

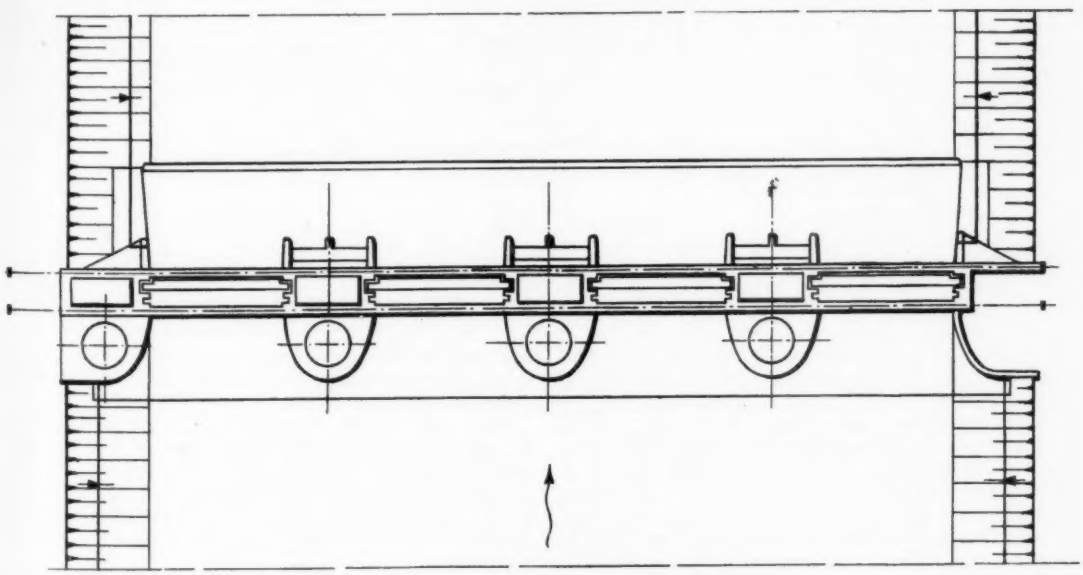


Fig. 16. Dr. Schulz's layout for a pier-type station

Grzywienski's conclusions are fully confirmed by the observed efficiencies of the hydraulic geometries of various Egyptian barrages. For instance, the piers, spans, apron profiles, etc., in both the Mohammad Aly and Edfina barrages are all the same, whereas the heading up in the flood of 1954 was 2 cm. only on the former but 13 cm. on the latter; this difference is ascribed to the much larger eccentricity of the layout of Edfina barrage as compared with the original Nile channel (see page 27, Volume II, as quoted above).

A graphical demonstration of Grzywienski's law is given in Fig. 13. The parabolic curve appearing in this drawing shows an excellent correspondence with the empirical points which represent in the same diagram a series of model tests as carried out at the Staatliche Versuchanstalt für Wasserbau, in Vienna, by Ehrenberger, for the Ybbs-Persenbeug power station on the Danube. The discharge of the prototype is assumed to be the same for all cases, viz., 10,000 cu. m. per sec. The eccentricities (in the sense of the term as explained above) and plotted as abscissae, while the ordinates represent the upstream levels, which, since the downstream level is constant, supply a measure of the losses of head.

The figures appearing in this diagram give the numbers of units placed on the left-hand and right-hand sides respectively of the main weir. It will be observed that the total number of these units is always the same, *i.e.*, eight. One of such experiments is shown in Fig. 14, which is reproduced here by courtesy of Prof. Grzywienski.

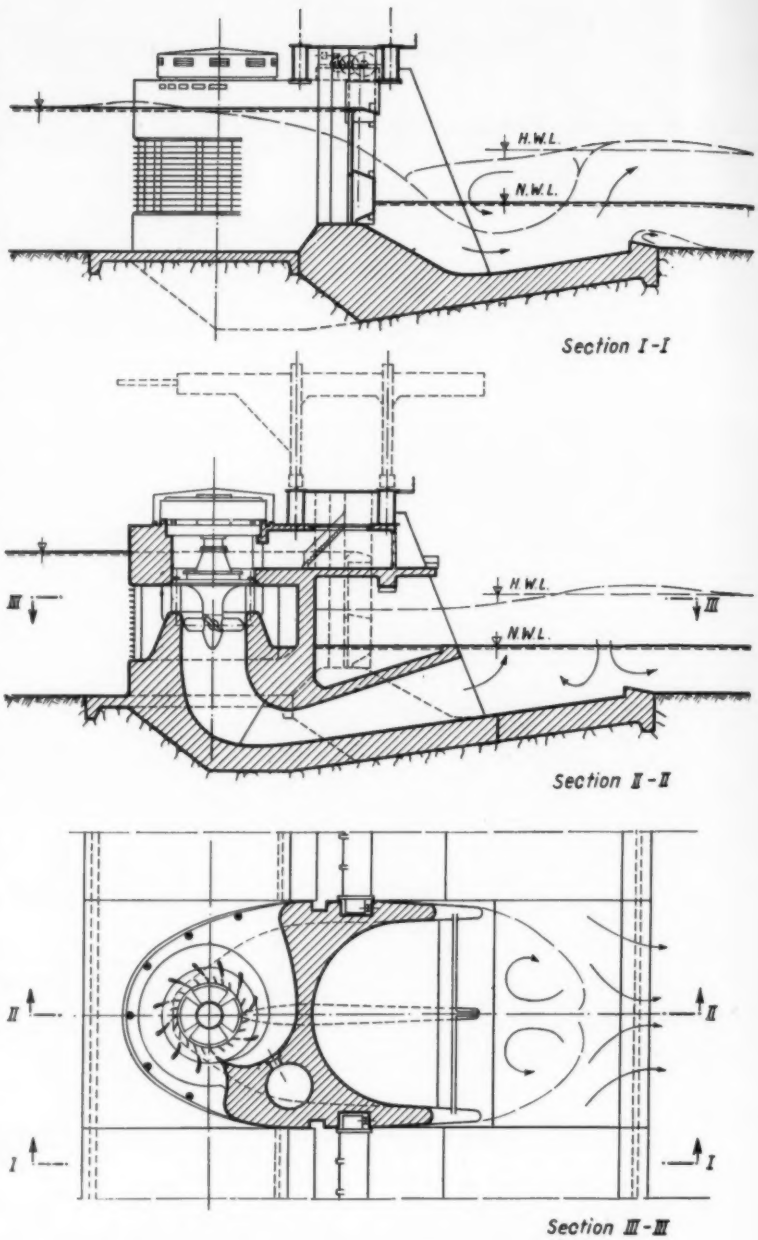


Fig. 17. Vertical and plan sections of Schulz piers

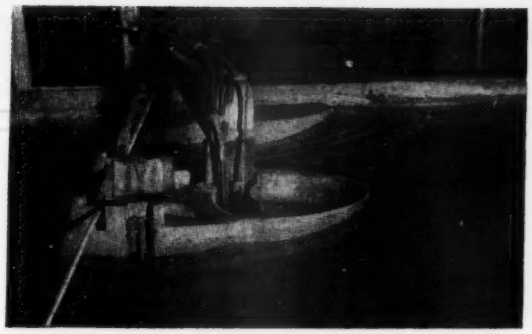
Broadly speaking it should be realised that this author concentrates his attention on the discharging capacity of the installation as a whole (particularly for flood conditions) rather than on the streamlines at the entrance to, and exit from, each individual turbine, on which depends the hydraulic performance of the unit. In comparing the relative advantages of the various layouts shown in Fig. 15[5] he tends, therefore, to prefer the arrangements shown in sketches 2 and 5. On the other hand, certain other writers concerned with turbine flow, recommend that each unit be placed in an independent pier, as shown for instance in sketch 4 in the same illustration.

Particular attention was devoted to the problem by Dr. A. B. Schulz,[6], who carried out, in the Wasserbaulaboratorium (Institut für Wasserbau) of the Technical University of Berlin-Charlottenburg, an extensive set of model tests on various problems of flow bearing on the optimum layout for a hydraulic power station.

[5] Abstracted from the publication quoted in the footnote on page 384.

[6] See "A New Type of Run-of-River Power Station," by Alexander B. Schulz, WATER POWER, May 1953, p. 177.

The arrangement he particularly favours is represented in Figs. 16 and 17, which are abstracted from the publication quoted. It will be observed that the water flows directly into the turbine without passing through guiding galleries, etc., which results in an appreciable saving of hydraulic energy. To prevent solid bodies being carried into the turbine, a semi-circular grid is provided to conform with the outer facing of the pier.



Right: Fig. 18. Model test of pier under heavy flood conditions

Below: Fig. 19. Diagrams of current trajectories round Schulz piers

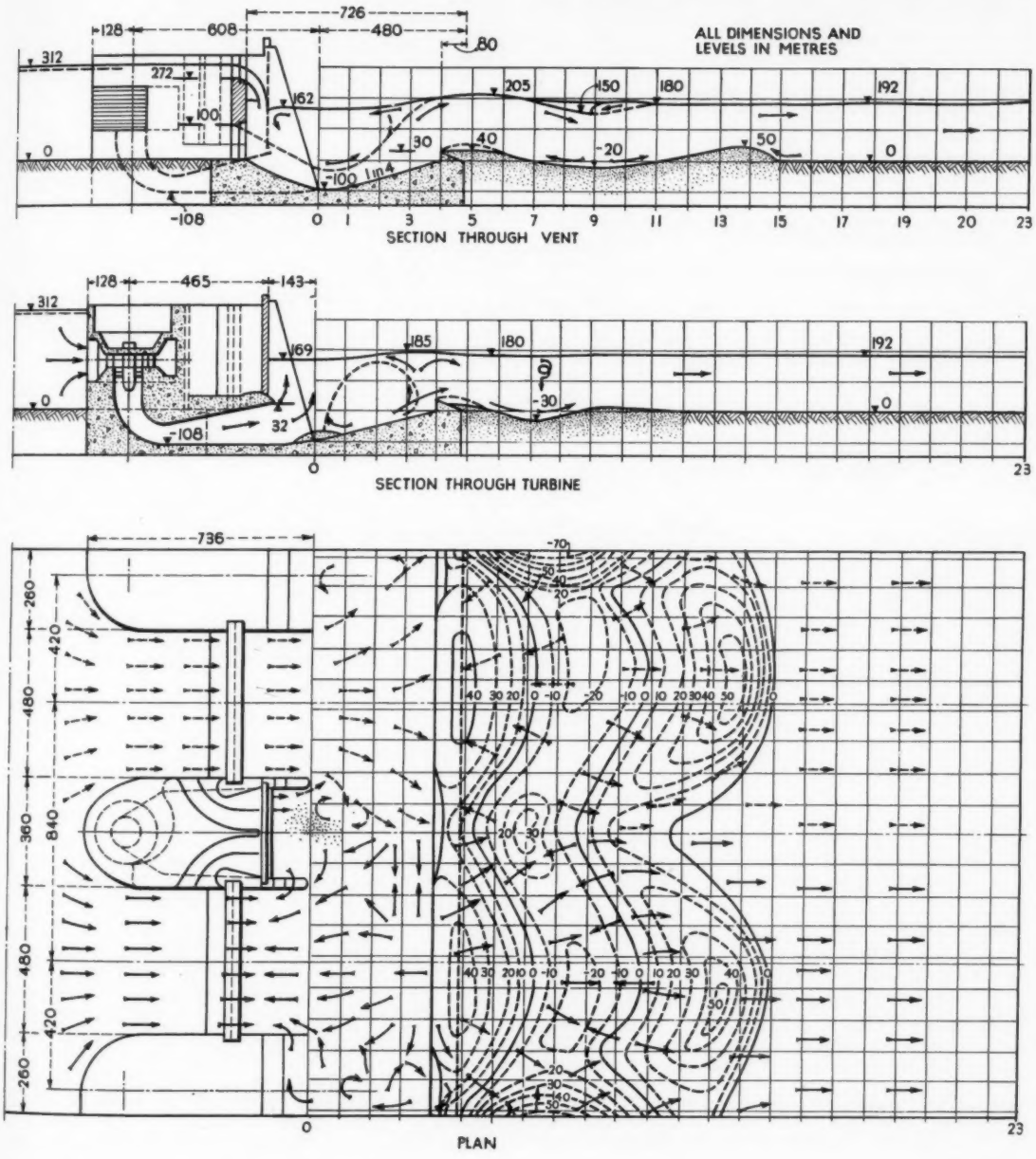


Fig. 18 is a model test for such a pier, with the total flood discharge of the river 28 times as great as the discharge passing through the turbines.

In Fig. 19 we have a complete picture of current trajectories upstream and downstream of the power station designed in this manner.

It will be observed that the apron extension is provided with an anti-scour lip, which has now become a standard feature of all irrigation works (at least in Egypt) built in alluvial channels. Little wonder, therefore, that the scour observed in these tests is negligible for all practical purposes. Details of the flow in closer vicinity to the turbine are shown in Fig. 21.

One of the advantages claimed by the inventor, Dr. Schulz,* is that the flow in the vents between the piers has an "ejector effect," viz., that it causes the downstream water level in the immediate vicinity of the weir to drop, and so augment the operating head, and hence the power, of the turbines. This particular aspect of the arrangement is shown in Fig. 22 which represents still another test carried out by the same author. It is obvious from this photograph that the water level in the tailrace of the turbine gradually rises (see coping of the dividing wall), which can only occur if, at the turbine, the water surface stands at a lower level

* The design is patented.

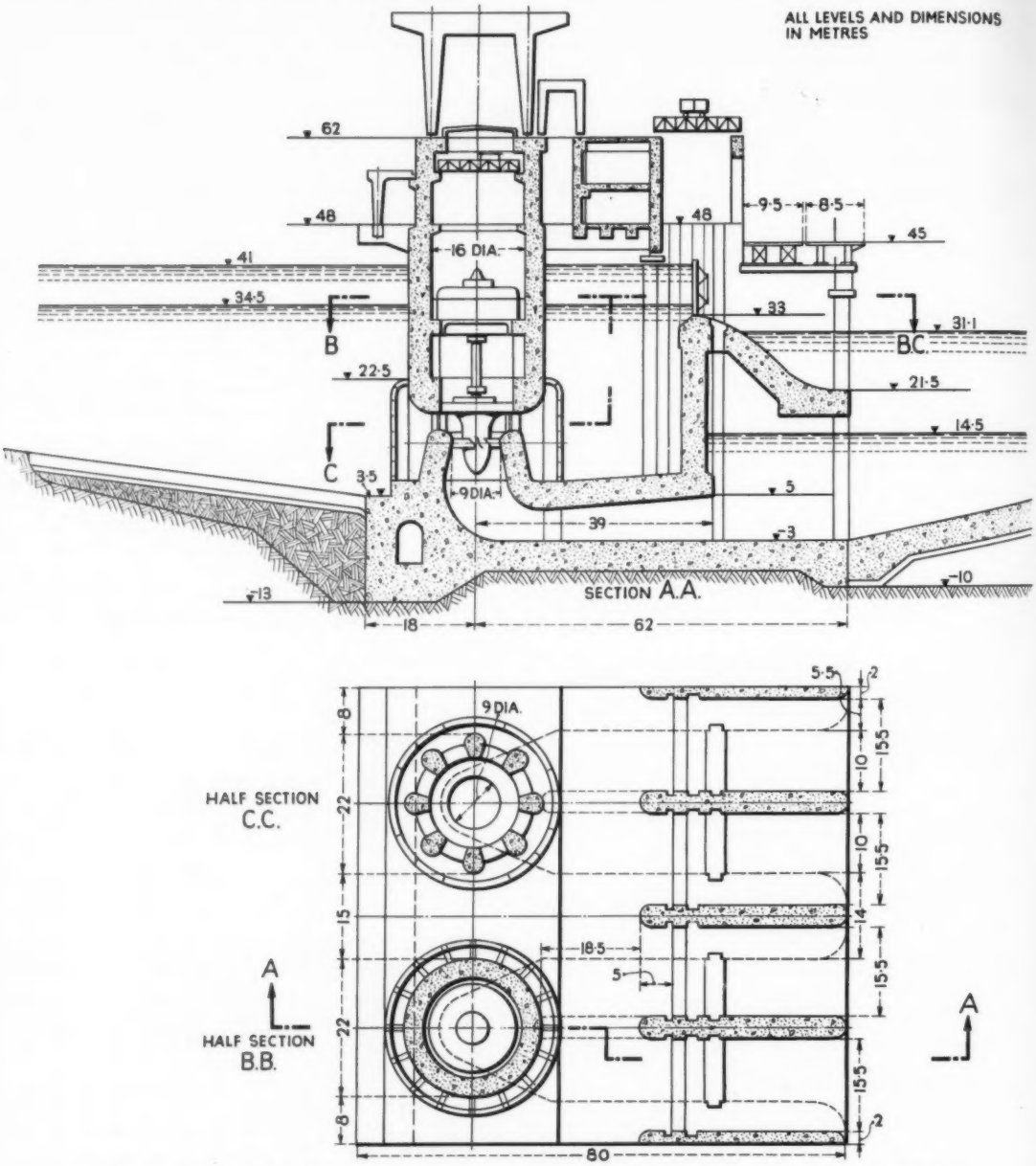


Fig. 20. Russian design in which the turbines are housed in towers separate from the dam

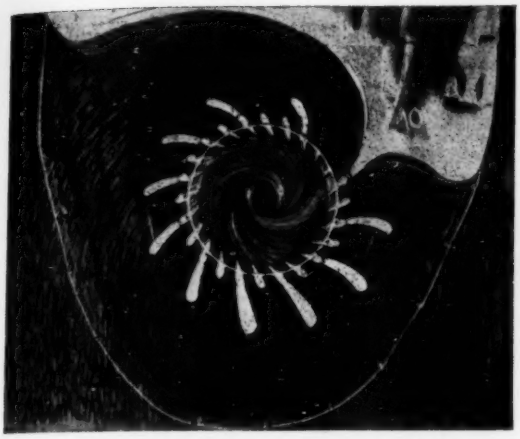


Fig. 21. Flow pattern round turbine when both vents are open

than in the downstream reach behind the station.

A Russian design,[7] not identical with, but incorporating a principle somewhat similar to, that of Dr. Schulz, is shown in Fig. 20. Here again the turbine is fed with water over all its perimeter, but is located in a special tower separated from the structure (dam) which resists against the head of water. The draft tube is located downstream of the dam. The arrangement of the gates, or stoplogs, which are required to isolate the turbine while it is overhauled or repaired, is not clearly shown in the drawing. The design is said to have been used for a station comprising both generating and pumping units.

[7] From Professor M. M. Grishin, "Hydrotechnical Works," Vol. II, p. 149; second edition. (The author of the design is N. M. Ivantsov) Moscow, 1955.

Fig. 22. Test by Dr. Schulz showing "ejector effect" between piers

Correspondence

Tunnelling Records

To the Editor of WATER POWER,

I was interested to read in the August edition of WATER POWER that contractors driving a tunnel in Perthshire for the North of Scotland Hydro-Electric Board had advanced 1,626 ft. during a 30-day period. This was a very fine achievement but I must challenge the claim that this constituted a record. As far back as June, 1956, tunnelling crews of my company, also working on the hydro-electric schemes, drove 1,837 ft. over the same period and, in fact, sustained this effort to cover 3,445 ft. in 60 days. These advances were made with normal tunnelling techniques in an 8½ ft. bed-width tunnel.

Neither of these advances was claimed as a record, however, because in the previous year my company's crews had established a world record by advancing 557 ft. in seven days (the period usually recognised in record attempts) in a tunnel of the same bed width. A few months earlier a British and European record of 428 ft. in a 10 ft. bed-width tunnel had been set up in the seven-day period.

These achievements which took place on the St. Fillans section of the Breadalbane scheme were the culmination of sustained rates of advance exceeding one mile a month on six tunnel headings.

It is interesting to note that modern techniques of tunnelling have speeded progress up so much that as many as 19 miles of tunnel have been driven in 2½ years by one contractor. One hundred years ago tunnelling figures were of the order of 8 miles in 13 years and the average daily rate of advance was 4½ inches. With the invention of dynamite and the percussion drill (first patented in 1867) this rate was increased to 6 ft. a day. The present rate reaches a maximum of 80 ft. per day—due, not so much to changes in method, but to improvement in equipment.

G. C. CUMMINGS,
The Mitchell Construction Company, Peterborough.

From page 383

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New Czechoslovak Standards for Concrete

A digest of the requirements of the new Czechoslovak standards for concrete to be used in hydraulic structures is given by Dr. Ing. Juraj Stork, Deputy Director of the Institute of Building and Architecture of the Slovak Academy of Sciences, Bratislava

GENERAL Czechoslovak standards for concretes, including those to be used in hydraulic structures, have been valid in Czechoslovakia since 1936, and were becoming obsolete, so in 1950 research work was started to provide a theoretical and experimental basis of special standards for hydraulic structures, which were then successively issued from 1954 to 1956. The new Czechoslovak standards for concrete for hydraulic structures consist of the following parts:

ČSN 73 20 20	Definition, Classification and Technical Conditions.
ČSN 73 20 21	Concrete Mix Components.
ČSN 73 20 22	Sampling and Scope of Tests.
ČSN 73 20 23	Testing of Concrete Components.
ČSN 73 20 24	Testing of Concrete Mix.
ČSN 73 20 25	Testing of Hardened Concrete.
ČSN 73 20 26	Concrete Mix Design.
ČSN 73 20 27	Concreting Work.

The total number of pages amounts to 142, which represents a booklet of considerable thickness. It is, of course, impossible to reproduce the standards in full in this article, and the author will therefore confine his attention to the chief characteristic features susceptible to arouse the interest of English-speaking readers.

Concrete for hydraulic structures is defined in standard ČSN 73 20 20 as concrete periodically or permanently washed by water or subject to effects of capillary action, and having qualities that enable it to resist the action of water.* Consequently, the characteristic features of concrete for hydraulic structures are: resistance to aggresivity of water, impermeability, durability, volume stability, strength and resistance to abrasion. Concrete for hydraulic structures is of the following types:

Normal concrete (H), which must show the required to resistance to action of water and strength.

Mass concrete (M), showing resistance to aggressivity, strength and low heat of hydration.

Watertight concrete (HV), distinguished by resistance to aggressivity, strength and impermeability.

Watertight mass concrete (MV), characterised by resistance to aggressivity, strength, impermeability and low heat of hydration.

Durable watertight concrete (VT), showing resistance to aggressivity, strength, impermeability and durability.

Watertight durable mass concrete (MVT), where resistance to aggressivity, strength, impermeability, durability and low heat of hydration are required.

In principle concretes are further subdivided into mass concrete (dimension of the section at least 2 m.), concrete for thick walls (dimension of the section 0·5—2 m.) and concrete for thin walls (less than 0·50 m.).

According to their strength, impermeability and durability concretes are further distinguished by their marks as explained later.

Technical Requirements

Technical requirements express standard claims set on particular characteristic features of concrete.

Resistance of concrete to aggressivity is evaluated on the basis of standard figures (see Table I). Whenever the concentration of the aggressive substances in water comes within 30% of the standard values referred to above (if leaching and acidity of water be considered) or if it amounts to 70% of the values mentioned, or if the construction is exposed to special strains, it is necessary to ask for the expert advice of a research institute. If uncertainty exists as to the opinion on aggressivity, comparative tests of resistance are to be carried out. The tests consist in storing one series of samples in the aggressive medium and the other series in non-aggressive water. The tests give a resistance factor computed from the result of the tests, the value of which should not exceed the value given by Table II. The resistance factor is the ratio between the strengths of samples stored in aggressive media and in non-aggressive water.

Impermeability. The standard provides three marks of impermeable concrete for hydraulic structures (see Table III). The selection of mark of concrete for hydraulic structures is effected according to Table IV.

Durability. The durability of concrete is characterised by the maximum number of cycles of alternating freezing and thawing of concrete samples, after which the factor of resistance to frost action is not reduced under 0·75 or after which the weight loss does not exceed 5%. The marks of durable concrete are given in Table V. The selection of marks of durable concrete is made according to Table VI.

Volume stability of concrete. Hitherto standards have included no definitions of marks for concrete characterised by their volume stability. Volume stability is given individual consideration according to the type of construction, technological procedure adopted and the type of concrete used.

Strength of concrete. Table VII shows the classification of concretes according to their compressive and bending strengths. It follows from the tables that when designing a concrete mix the strength must be 15% higher than the strength achieved on site in control tests. At the same time, concretes for surfacing

* i.e., sweet water.

TABLE I.—STANDARD NUMBERS FOR CLASSIFICATION OF AGGRESSIVE WATER

Type of aggressivity	Characteristic features of aggressivity	Unit	Concrete is surrounded by								
			considerable quantity of flowing water in a stream or in highly permeable soil (coarse gravel, fissured rocks)			considerable quantity of standing water or smaller quantity of flowing water (permeable soil)			little permeable soil or only occasional contact with water		
			normal Portland cement	slag Portland cement	trass cement	normal Portland cement	slag Portland cement	trass cement	normal Portland cement	slag Portland cement	trass cement
			waters in contact with concrete are considered as aggressive when reaching values:								
Leaching	temporary hardness of water	degree German	6·0	4·5	3·0	4·0	3·0	1·5	2·0	1·0	—
Water acidity	index *pH*	—	7 if temp. hardness <24° 6, 7 if temp. hardness >24°		6·7	7 if temp. hardness <24° 6, 7 if temp. hardness >24°	6·7	6·4	6·5	5·8	5·0
CO_2		mg/l	up to 6° Germ.								
			0	3	5	0	5	8	5	10	20
			more than 6° Germ.								
			2	4	7	6	10	15	10	25	—
Sulphatic	SO_4'' ion concentr.	mg/l	80	250	500	200	400	800	250	600	—
Magnesitic	Mg'' ion concentr.	mg/l	200			400			1000		

TABLE II.—LIMITING VALUES OF THE RESISTANCE FACTOR

Concrete surrounded by	Value of resistance factor
considerable quantity of flowing water in a stream or in highly permeable soil (coarse gravel, fissured rocks)	0·90
considerable quantity of standing water or a smaller quantity of flowing water (permeable soil)	0·85
little permeable soil or only occasional contact with water	0·80

require a minimum strength of 135 kg./cm². in 28 days, whereas the strength of 105 kg./cm². is sufficient for core concretes, of course under the assumption that the primary requirements of impermeability, durability, etc., are satisfied. If the temperature sinks below 0°C., the curing of fresh concrete can be omitted only if the concrete achieves 60% of its designed (or standard) strength in 28 days, and in any case the minimum strength of 80 kg./cm². If temperatures lower than −10°C. are expected, it is imperative to know, for the restriction of protective measures, whether at the time of the temperature drop under −10°C. the minimum strength 120 kg./cm². was achieved or not. Further concrete layers may be poured only if the underlying concrete reached the minimum strength of 25 kg./cm².

The same strength is required when side shuttering is to be stripped.

Notation of concretes for hydraulic structures. Concretes for hydraulic structures are characterised by their marks; *e.g.*, impermeable and durable concrete up to 50 cm. thickness subject to maximum head up

TABLE III.—MARKS OF WATERTIGHT CONCRETE FOR HYDRAULIC STRUCTURES

Mark	Maximum head during test	Time of action of maximum head	Total time of test	Total kg/cm².h
	kg/cm²	hours		
V_4	4	8	32	80
V_8	8	8	64	288
V_{12}	12	8	96	624

TABLE IV.—CHOICE OF MARK OF WATERTIGHT CONCRETE

Characteristic feature	Massive construction			Thick-walled constructions			Thin-walled constructions		
Maximum head acting on structures (m.)	up to 20	from 20 to 60	from 61 to 100	up to 15	from 16 to 30	from 31 to 50	up to 7	from 8 to 15	from 16 to 30
Recommended mark of watertight concrete	V_4	V_8	V_{12}	V_4	V_8	V_{12}	V_4	V_8	V_{12}

TABLE V.—MARKS OF DURABLE CONCRETE

	T_{50}	T_{100}	T_{150}
Maximum number of cycles of freezing and thawing of concrete samples stored in water for 28 days, after which the factor of frost resistance does not drop under 0·75, or after which the weight loss is less than 5%	50	100	150

TABLE VI.—CHOICE OF TYPE OF DURABLE CONCRETE

	Climatic conditions			
	mild*		severe*	
Number of fluctuations of water level during winter time on the surface of concrete alternatively submerged or washed by water	up to 50	more than 50	up to 50	more than 50
Recommended mark of type of durability of concrete	T_{50}	T_{100}	T_{100}	T_{150}

* The calculation of equivalent time is specified in standard CSN 73 20 25.

Climatic conditions are considered to be mild where the average temperature in the course of last 30 years in the coldest month of winter time is up to −5°C. under frequent alternation of frost and thaw, or up to −10°C. under longer duration of frost uninterrupted by thaws.

Climatic conditions are considered to be severe where the average monthly temperature in the course of last 30 years of the coldest month of winter is under −10°C. and where the number of alternations of frosts and thaws is more than 25 for one winter

TABLE VII.—MARKS OF CONCRETE ACCORDING TO STRENGTH

Mark of concrete	Average compressive cube strength of concrete*		Average bending strength of test beams	
	Control tests	Preliminary tests	Control tests	Preliminary tests
	kg/cm²			
60	60	70	8	10
80	80	95	12	14
105	105	120	16	18
135	135	155	20	24
170	170	190	26	30
250	250	280	38	44
330	330	360	50	58

* The values tabulated refer to strength of hardened concrete cubes, of 200 mm. side, after 28 days of hardening in moist atmosphere (cf. standard CSN 73 20 25) regardless of other properties of concrete such as consistency, maximum particle size, etc

TABLE VIII.—CLASSIFICATION OF AGGREGATES

Components		Particle size mm.
Deleterious substances	Clay	0·000 to 0·005
	Earth (dust)	0·005 to 0·05
Aggregate	Filler (powdered)	0·05 to 0·15
	Fine particles	0·15 to 5·00
	Coarse particles	5·0 to 150·0 or $D_{max.}$
	Oversize	more than 150·0 or $D_{max.}$

TABLE IX.—PARTICLE SHAPE

Particles	Ratio of dimensions		
	length / thickness	length / width	thickness / thickness
Globular, cube-shaped	<1·5	<1·5	<1·5
Flat-shaped	>1·5	<1·5	>1·5
Elongated, needle-shaped ...	>1·5	>1·5	<1·5

to 10 m., exposed to more than 50 cycles of freezing and thawing during winter and having the strength of 170 kg./cm.² in 28 days receives the notation $V_6\ T_{150} - 170$.

ČSN 73 20 21—Components of Concrete Mix

Components of the concrete mix considered by the standard are: (a) binders, (b) finely ground (powdered) admixtures (inert fillers), (c) aggregate, (d) chemical mixtures, (e) water, (f) air.

The definition and specification of binders are provided by special standards (in the process of revision at present). Only special requirements related to hydraulic structures are considered by the present standard.

The heat of hydration of Portland cements used for thick-walled and mass-concrete constructions should not exceed 50 Kcal./kg. in 3 days and 65 Kcal./kg. in 7 days (with a tolerance of 5 Kcal./kg.) measured by the thermos-jar method. For winter concreting Portland cements are admitted producing heat of hydration of 60 Kcal./kg. in 3 days and 75 Kcal./kg. in 7 days. The fineness of grinding of Portland cement is

TABLE X.—REQUIREMENTS FOR COARSE AGGREGATES

Properties	Unit	Class of aggregate			
		I	II	III	IV
Durability of gravel determined by the number of freezing and thawing cycles after which the weight loss should not exceed 5 per cent.	cycles	200	100	100	50
Water-absorbing capacity	per cent of weight	max. 1·5	max. 1·5	max. 2·0	max. 2·5
Soundness of gravel (weight of water-worn particles in Na_2SO_4 test)	per cent of weight	2	3	4	5
Weight per cent. of lightweight particles (weight of unit volume <2·0 g./cm.³) ...	per cent of weight	3	5	5	10

determined by its lower and upper limit. The variation of results of the fineness of grinding given by the standard should not exceed ±30% and ±15% for screen analysis and specific-surface test respectively. Portland cements not satisfying this condition should not be used in the same construction in which a satisfactory cement was used. The initial set of cement at a temperature of 20°C. ± 2·5°C. should occur in not less than 120 min. and the final set should commence earlier than 10 hours after the mixing of cement with water was effected. Simultaneously the initial set determined from samples taken from two different parts of the same wagon shipment of cement should not differ more than 20% from the arithmetic mean, and individual values from different wagons more than 20% from the arithmetic mean of all results together.

TABLE XI.—MECHANICAL AND PHYSICAL PROPERTIES OF ROCKS

Properties	Class of stone			
	I	II	III	IV
	severe climate		mild climate	
Compressive strength of water-saturated stone	min. 800	min. 800	min. 600	min. 400
Compressive strength of dry stone ...	min. 1,000	min. 1,000	min. 625	min. 500
Compressive strength of samples exposed to due number of cycles of freezing and thawing	min. 600	min. 600	min. 375	min. 300
Factor of softening (ratio of compressive strength of water-saturated stone to compressive strength of dry stone)	0·8	0·8	0·8	0·8
Water absorbing capacity (per cent. of weight)	max. 1·5	max. 1·5	max. 2·0	max. 2·5
Number of cycles of freezing and thawing of samples subject to durability test (factor of resistance to frost action 0·75 or weight loss max. 5%)	200	100	100	50
Unit weight of stone g./cm.³	min. 2·5	min. 2·4	min. 2·3	min. 2·3
Allowed percentage of test results of samples showing 10% lower compressive strength in saturated condition (from the total of control tests)	3 less than 800, min. 720 kg./cm.²	5 ditto	10 less than 500, min. 450 kg./cm.²	10 less than 400, min. 360 kg./cm.²
Allowed percentage of results of durability tests showing lower factor of frost resistance (lower than 0·75, min. 0·70) from the total of control tests	3	5	5	10

TABLE XII.—SEQUENCE OE GRADING SCREENS

Shape of aperture	Square				Circular						
Clear diameter of mesh mm.	0·15	0·30	0·60	1·20	2·5	5	10	20	40	80	150
Equivalent dimension of square aperture mm.	—	—	—	—	2	4	8	16	32	64	120

TABLE XIII.—GRADING OF FINE PARTICLES

Screen size mm.	0·15	0·30	0·60	1·2	2·5	5
Weight per cent. of undersize particles	1—10	5—30	18—50	30—70	60—90	85—100
Allowed variation from optimum grading	±3	±5	±7	±7	±7	—

The standard strength of cement after 28 days of hardening should be limited, in addition to the maximum value, by the upper limit, which should not differ more than +20% from the mean value of the average of all tests up to class* 350 of compressive strength and +15% for classes higher than 350. These regulations follow the aim of achieving deliveries of homogenised cement to the sites.

As powdered admixtures, basic slag, pozzolans and inert materials are admitted.

Pozzolanic activity of admixtures is determined from its formula

$$P_S = P_P - N + 5$$

Where

P_S = strength of pozzolanic cement,

P_P = strength of pure Portland cement (without pozzolanic admixtures),

N = per cent. of finely ground pozzolanic admixture.

The hydraulically inert admixtures require that percentage reduction of standard strength does not exceed the percentage of admixture added.

* Czechoslovak cements are classified according to their standard compressive strength, therefore class "350" means the standard compressive strength of 350 kg./cm.² after 28 days of hardening.

Aggregate

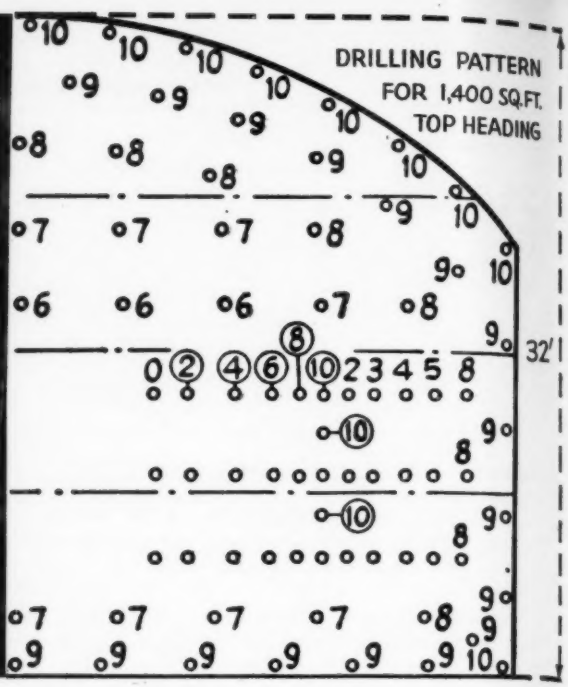
The classification of aggregates in this standard follows the pattern of Table VIII. Further, the procedure of petrographic analysis is specified. Petrographic and mineralogical anaylsis is unnecessary if the volume of concrete in the construction does not exceed 10,000 cu. m. In particular the standard species the determination of the percentage content of lightweight particles coming from rocks with specific gravity less than 2·00 g./cm³., its percentage content of particles of amorphous silicates, and the percentage of coal and lignite as well as of shales and micas.

Particle shape. According to their shape the particles are classified as in Table IX. The amount of elongated and needle-shaped particles should not exceed 15% (by weight) of the total. If this percentage is higher, the decision concerning the use of such a material should be made on the basis of comparability tests and economic considerations.

Coarse aggregate for concrete to be used in hydraulic structures should satisfy the requirements in Table X. Mechanical and physical properties of rocks from which crushed stone is produced, must satisfy the values of requirements for each class of stone given in Table XI. If the rock does not satisfy the condi-

TABLE XIV.—GRADING OF COARSE AGGREGATE

Maximum particle size mm.	5/20	5/30	5/40	20/40	20/60	30/70	40/80	80/150	Total must be equal %
	Recommended proportioning by weight %								
40	45—60	—	—	40—55	—	—	—	—	100
60	35—50	—	—	—	50—65	—	—	—	100
70	—	45—53	—	—	—	45—58	—	—	100
80	25—35	—	—	25—35	—	—	35—50	—	100
80	—	—	50—65	—	—	—	35—50	—	100
150	—	—	30—40	—	—	—	25—35	30—45	100
150	15—25	—	—	15—25	—	—	25—35	30—45	100



Harrsele—a remarkable tunnelling operation in Sweden

Since the tunnelling operations began at Harrsele in northern Sweden the fast progress made there has been followed with great interest by construction and mining engineers throughout the world. On the 1,400 sq. ft. (32 ft. high, 49 ft. wide) top heading of the two-mile long discharge tunnel (the remaining bench to be excavated amounted to another 1,400 sq. ft.), the tunnelling crews beat the world tunnelling record in August 1955 with an advance of 585 feet, achieved by rounds of 26.4 feet. The work was carried on in three shifts; one for the drilling and blasting, and two for the mucking-out. On December 21, 1955, the break-through took place *—three months ahead of schedule.*

The 'Swedish Method' again!

The rock drills chosen for the Harrsele tunnel were exclusively Atlas Copco. Most of these were fitted with Sandvik Coromant steels. These lightweight drills and integral steels represent the basis of the 'Swedish Method'. To begin with, both were developed to work together so that drill and steel gave a completely balanced performance. Atlas Copco drills are small and compact. This means more drills at the face and a heavier concentration of drilling. The Sandvik Coromant steels with their new revolutionary SR anti-corrosion treatment have up to 50% longer life than untreated steels. The following drilling figures from the drifting at Harrsele show the impressive results to be gained from the 'Swedish Method'.

Advance per round	**26.4 feet**
Number of cu. yds. per round	**1,375**
Number of holes per round	**150**
Footage drilled per round	**3,940 feet**
Footage drilled per cu. yd.	**2.85 feet**
Number of drills and drillers	**21**
Number of man-hours per cu. yd. *(drilling, charging and blasting)*	**0.122**
Drilled footage per man-hour	**53.5 feet**
Advance per month *(27 working days)*	**580 feet**

Atlas Copco AR compressors supplied the air

The rock drills were fed from a battery of Atlas Copco AR 4E compressors. The famous AR-series give more air to the h.p. than other machines of their class.

World-wide sales and service

The Atlas Copco Group puts compressed air to work for the world. It is the largest group of companies specialising solely in the development and manufacture of compressed air equipment. It embraces Atlas Copco companies or agents manufacturing or selling and servicing Atlas Copco equipment in ninety countries throughout the world. For further details of the equipment featured here, contact your local Atlas Copco company or agent, or write to Atlas Copco AB, Stockholm 1, Sweden.

Atlas Copco *Manufacturers of Stationary and Portable Compressors, Rock-Drilling Equipment, Loaders, Pneumatic Tools and Paint-Spraying Equipment*

tions of compressive strength, crushed stone may be used in concrete only if the concrete produced with the aggregate satisfies the conditions of strength, durability and volume stability.

The maximum particle size must not exceed two-thirds of the clear distance between reinforcement bars and shuttering, or the particle size must not exceed one-fifth of the minimum dimension of the construction concerned. This dimension is reduced to one-third where flat constructions are concerned.

For the determination of grading the Czechoslovak standard commission has adopted a series of Soviet screens conforming to Soviet standard GOST 4797-49 having the sequence given in Table XII. The grading of fine particles must be contained within the limits given in Table XIII: The limiting values for the grading of coarse aggregate are given in Table XIV. The optimum grading of a mixture of fine and coarse aggregate, the grading of which varies within limits mentioned above, will be decided by the maximum water contents necessary to achieve the required properties of concrete mixes containing the minimum weight of cement and having the desired degree of workability.

The allowed overlapping of individual fractions is expressed by Table XV. The maximum permitted quantity of deleterious substances in fine aggregate is given in Table XVI. For coarse aggregate the contents of deleterious substances is limited as shown in Table XVII. The limiting values of agents contained in mixing water are shown in Table XVIII.

(To be continued)

New Zealand Annual Report

THE New Zealand Ministry of Works Statement for the year ended March 31, 1957, reveals that in the hydro-electric field the year was one of achievement and of intense continuing activity. Two stations were brought into commission, affording much-needed relief to a critical power situation. At Roxburgh the first four generators, totalling 160 MW, were placed in service, and as we reported in our September issue, orders for the remaining four sets have now been placed. Work also continued at Hawea, where the lake is being controlled to regulate the flow to Roxburgh. The other station completed during the year under review was Whakamaru, on the Waikato in the North Island, contributing 100 MW of capacity.

Construction proceeded at three other new stations on the Waikato—Atiamuri, Ohakuri and Waipapa. The 84 MW Atiamuri station is scheduled for operation in 1959. The river was diverted in January 1957, excavation for the dam left abutment and right-bank cut-off wall was completed, and concreting and placing of earthfill were proceeding satisfactorily. Part of the permanent structure above the diversion culverts was about 75% concreted, and the steel penstocks were being fabricated.

At Ohakuri site investigations were carried forward, and stripping and excavation were commenced in the forebay, power-house and spillway areas. Pilot drives had been completed for the diversion tunnel.

At Waipapa work proceeded on the excavation of the diversion cut, using the comparatively new technique of paddock blasting.

To meet the anticipated increase in load before Atiamuri station is commissioned in 1959, a steam station is being built at Mercer and a geothermal station at Wairakei, both due for service in 1958. The big block of base-load power being brought into the system by these stations, and also the possibility of increasing flow in the Waikato due to diversion of water into its upper watershed, thus raising the plant factor of existing stations, has introduced a problem new to New Zealand. Where in the past the hydro-stations have been built to fit the load curve, the geothermal stations, in particular, will work at practically continuous output; and so as to cater for the high loads of the business hours additional plant working at these peak periods is required. To provide peak power to effect full utilisation of this base-load power, various solutions are under consideration, including the addition of a fourth machine at Atiamuri and Ohakuri and of extra machines at existing Waikato stations.

Of the forward projects the outstanding scheme is the 480 MW Benmore station on the Waitaki in the South Island. Design studies were made for both concrete and earth dams, and the scheme adopted is for a 17 million cu. yard dam of locally available earth materials, rising about 315 ft. above tailwater and impounding New Zealand's largest man-made lake. To assist the accumulation of the vast number of data from which the design report is now being prepared, various special measures were adoped to secure vital information from the site for early investigation. Site contour plans, for example, were speedily prepared by using the Lands and Survey Department's up-to-date aerial mapping service in conjunction with ground-control survey by the Ministry of Works.

Prospecting and investigation work for new power projects was continued in the Rangitaiki River and Bay of Plenty areas, and also in the Turangi-Waiouru areas of the Upper Waikato River. The hydro resources of the North Island have hitherto been assessed at 125 MW, but evidence is accumulating to show that the top limit is likely to be much higher. Large power potential exists in the Tongariro, Rangitaiki, Mohaka, Wanganui and Egmont catchments, but cost and feasibility of development have yet to be assessed for individual projects.

Vertical Turbine Guide Bearings. Mr. Englesson, the author of this article published in our August issue, has pointed out a typographical error in formula (8) on page 294, where the root sign should extend over d, thus:—

$$h_o = 0{\cdot}07\ \sqrt{0{\cdot}001\ d}\ \text{mm}.$$

In the following line of the article, d should obviously be given in millimetres. Formula (8) has also been quoted incorrectly on page 296, first column, line 24, where the term 0·001 has been omitted.

Atlas Copco produce world's lightest motor drill

From Atlas Copco, the world's largest manufacturers of pneumatic rock-drilling equipment, comes an entirely new motor drill. It is the Atlas Copco *Cobra*, backed by 50 years' experience of rock-drilling equipment, and developed after extensive field tests.

Weighing a mere 53 pounds, the Atlas Copco *Cobra* is undoubtedly the lightest, handiest motor drill ever brought out. (The usual weight of a motor drill is around 80 pounds.) Yet despite its low weight the Cobra is able to put up a *higher footage* under actual working conditions than other, *heavier* motor drills. It is powerful, robustly constructed and, above all, *100 per cent self-contained!* One man can carry it and start it up *anywhere*.

New exclusive drill features

The Atlas Copco Cobra has 100 per cent air flushing from the built-in compressor. As no exhaust gases are used for flushing, troublesome decarbonizing is eliminated. Another *first-ever* feature is the free-wheeling mechanism for easier starting and more rapid steel changes. The Cobra also incorporates a unique new method of automatic rotation of the drill chuck, a floatless carburettor enabling drilling up to a 45 degree incline and a pull-type starter. The Cobra drills 100 feet to the gallon, has a drilling rate of 26 feet per hour, and can drill holes up to 13 feet in depth.

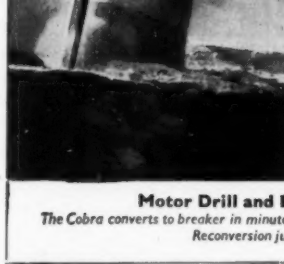
The right steels for the Cobra

The Cobra—like all Atlas Copco drills—has been developed for use with *Sandvik Coromant* steels, the world's most widely-used integral drill steels. This, of course, adds considerably to the performance of the Cobra. *No drill or steel developed separately could possibly give such equivalently high results.* Atlas Copco drills fitted with Sandvik Coromant steels have proved an unbeatable drilling unit, responsible for the drilling of no less than one billion feet each year.

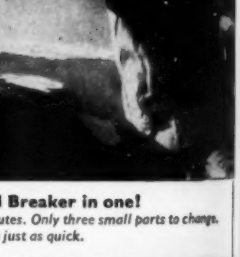
World-wide sales and service

The Atlas Copco Group embraces Atlas Copco companies or agents manufacturing or selling and servicing Atlas Copco equipment in ninety countries throughout the world. For further details of the equipment featured here, contact your local Atlas Copco Company or Agent, or write to Atlas Copco AB, Stockholm 1, Sweden.

Motor Drill and Breaker in one!
The Cobra converts to breaker in minutes. Only three small parts to change. Reconversion just as quick.



Easily carried anywhere! *Perfectly-balanced carrying handle. Moulded back frame for transporting cross-country.*

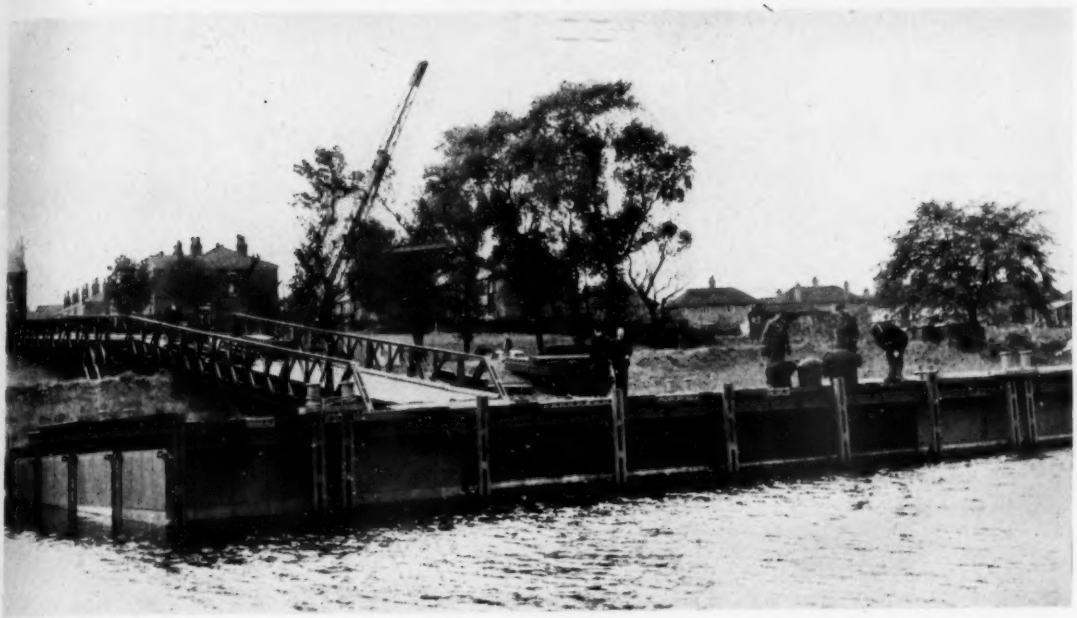


Grinder driven from the Cobra! *A specially light drill steel grinder, powered through the crankshaft, can be supplied if required.*

THE **Atlas Copco** GROUP OF COMPANIES

Manufacturers of Stationary and Portable Compressors, Rock-Drilling Equipment, Loaders, Pneumatic Tools and Paint-Spraying Equipment

Flotation Unit for Pontoon Construction



A FLOTATION unit, or pontoon, known as the "Storey Uniflote," has recently been designed and manufactured by Thos. Storey (Engineers) Limited, Stockport. Designed in the first instance for use with Bailey bridging, the Uniflote embodies the same basic idea of unit construction and should have a wide field of usefulness to civil-engineering contractors needing to construct waterborne stagings for temporary landing facilities, pile driving, setting cofferdams, and so forth.

Each unit is basically a rectangular steel-framed tank, 17 ft. 4 in. long, 8 ft. wide and 4 ft. deep. Special couplers arranged round the sides and ends enable the units to be connected together, side-to-side, end-to-end or side-to-end. The lower couplings, which are below water level, are in the form of hooked lugs which are engaged automatically by slightly tilting one unit relative to its neighbour and then allowing it to return to the horizonal position. The top couplers only require location pinning at deck level by inserting the pins through eyeholes in the male and female couplers.

Two watertight bulkheads are built into each unit, thus forming three watertight compartments. Each compartment is fitted with a manhole in the deck, and a hose-connector and standpipe. By pumping water into the compartments, the units may be ballasted, and such ballast may be ejected by compressed air.

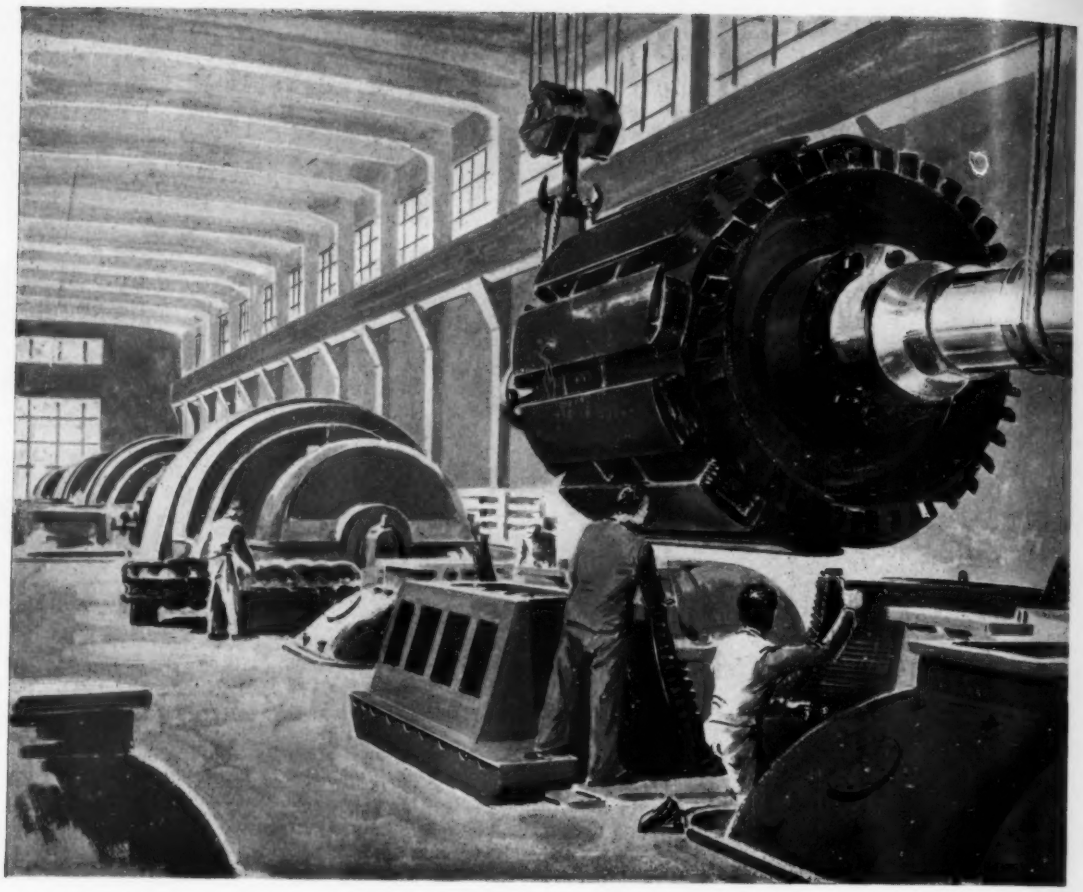
The weight of each unit is 3 tons and its flotation capacity 0·32 tons per in. of draught; thus, unloaded the draught is 9 in. and a superimposed load of approximately 12 tons is required to reach submersion point. Normally, in still or near-still water, a free board of 6 in. is recommended, and in that state each unit will carry a load of about 10 tons.

Protective runners are fitted to the underside, and gunwales mounted on the deck provide a means of attaching various forms of superstructure. A range of inter-float connectors is also being produced. These are steel frames carrying at their ends the same couplers as those on the units, thus enabling units to be connected at various spacings. Uniflotes so connected can be fitted with the same standard decking as is used on the Bailey bridge. Although initially intended to carry Bailey bridges, the units provide a system of building up floating platforms of various shapes and sizes to suit the requirements of the contractor.

The landing stage shown in the above illustration, will eventually be sited at the newly developed port of Nkata Bay on Lake Nyasa. The port will be served by lake steamers of about 500 tons. As shown in the illustration, Bailey bridging is used for access to the landing stage which is formed of flotation units.

Allis-Chalmers Research Centre

Groundbreaking ceremonies for a new $3,250,000 (£1,166,000) engineering development and research laboratory centre at the Harvey, Illinois, Works of the Allis-Chalmers Manufacturing Co. were held recently. Major structures to be built include a central engineering building, an engine and material-handling product development laboratory and an engine test wing accommodating 32 engine dynamometers. When completed, the engineering and research facilities of the new laboratory centre will work on the development of material-handling equipment and engines for Allis-Chalmers manufactured farm machinery and earth-moving equipment, as well as commercial engines such as those used in power shovels, cranes, generator sets, and other contractor's machinery.



Brown Boveri supplied the five alternators for Riddes, owned by the Forces Motrices de Mauvoisin S.A., Sion; with its output of 335,000 kVA this is the largest hydro-electric plant in Switzerland. Three 60,000 kVA alternators were also supplied for Fionnay, the upper stage of this power scheme

Our life each day

is largely dependent upon electricity. Light, power, heat, radio, transport: each of these needs the energy obtained from the country's natural resources. Brown Boveri products assist in exploiting these resources and, by placing them at your disposal, help to raise your standard of living.

BROWN BOVERI

Some of our products:

Steam- and gas-turbine plants · machines and equipment for atomic power plants · electrical equipment for hydro-electric and diesel stations · airblast circuit-breakers and transformers for up to 400 kV · protective and regulating systems · mutators · contact converters · electric motors and control gear · electric furnaces · welding equipment · carrier equipment for power system communications · broadcast and telegraphic radio transmitters · television transmitters · transmitting and rectifier tubes · electrical equipment for locomotives, trams, trolleybuses · marine propulsion machinery · turbo-compressors · blowers · exhaust-gas turbochargers

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Abstracts from the World Technical Press

Basic Experiments on Stilling Basins Without Friction Blocks

This paper gives an account of basic investigations conducted on a 1/60 scale model of the Kaddam spillway with a view to finding out whether the increase in width or depth of a stilling basin, set up without any friction blocks, would promote the formation of a hydraulic jump and improve the dissipation of energy. The size of the stilling basins tested varied between 10 and 18 ft. in depth and 30 and 60 ft. in width; the effects of low obstructions within the basin at various positions, and a stepped end-sill were also investigated. No stable hydraulic jump was formed either with these devices or by increasing the depth or width of the stilling basin. Further basic experiments of the same nature are contemplated. A further and more fundamental aspect of the problem is to what extent the scale of the model affects the formation of the hydraulic jump. (R. K. V. Narasimham and G. R. Krishnamurthy, *Irrigation and Power*, Vol. 14, No. 1, January 1957, p. 46, 7 pp., 4 ff.)

Fish versus Dams

How far the fish v. dam conflict can affect public interests is sharply illustrated by the interruption of all work on Tacoma City Light's proposed Mayfield dam on the Cowlitz River, just because a fish hatchery would have been inundated by the new reservoir. The stakes, in this particular instance, are, on one side, a profitable run of salmon likely to be jeopardised by a dam, and, on the other, an adequate future power supply for a population of 157,000. Proceeding from an account of the Tacoma case, the article reviews the various aspects of the fish problem as interwoven with dam building. The advantages and drawbacks of the various devices contrived to help upstream migration, such as ladders, elevators and lifts, are discussed; here, the major problem is that of attracting fish to the device. The Corps of Engineers has largely financed major research projects involving the use of light, sound waves, magnetic fields, and electricity. So far, electricity appears the best "fish guider": two nets of electrodes establish an electrical field in the water; upon hitting this field, fish recoil, seek to work around it and, eventually, wind up in the "trap." At Brownlee dam, Idaho Power Co. is using temporarily an electrode system which forces fish into a trap on the river bank; this trap is hoisted periodically, and the fish are dumped into a 1,000 gallon tank truck, hauled around the dam, and poured back into the river. The true performance of this scheme has yet to be evaluated, since it was first put into operation after the recent round of steelhead trout. Dam builders are now turning their attention to migration in the opposite direction, that is to say, to moving fingerlings downstream. Tacoma City Light are operating a skimmer device which is being hailed cautiously as a possible answer to the problem. Fingerlings, attracted by strong current near the reservoir top, pass over a screen and are carried through a pipe to the river below the dam. Fish experts say, however, that at least two generations of salmon, i.e. 8 to 12 years, will be required to prove the effectiveness of the skimmer. Puget Sound Power and Light have adopted the ski-jump water chute, after they had ascertained by experiments that small fish can drop up to 300 ft. with virtually no casualties if they fall in a stream of water into a deep pool; this water chute spouts a stream from the reservoir into the river 250 ft. below, safely beyond the spillway base. McNary, The Dalles, Ice Harbor and Rock Island dams have no special facilities for carrying fish safely downstream: they all use Kaplan turbines which have proved to be less harmful than the Francis type. Attempts to solve the problem by other methods are also under consideration. At McNary, for instance, an artificial spawning area is contemplated duplicating what fish experts consider the best stream conditions for spawning salmon. Salmon will be caught in large pools and, if spawning occurs, fingerlings will later be returned to the river for migration to sea. The big question in this instance is, will salmon accept or reject an artificial environment while following a reproductive instinct dictated by nature? Results will show. In another experiment, Washington State Fisheries Department will dump 180,000 differently tattooed fish at various points above Big Cliff dam on the Santiam River in Oregon, which approximates McNary in height. It will then set nets below the dam to catch the fish and find out what the spillway or turbine beating did to them. At Big Sandy dam, Portland General Electric is to experiment soon to determine the proper size of fish screen openings and whether sound can be used to attract fish to traps and skimmers. The idea here is to see if the recorded roar of turbulent water, played somehow under water for the fish to hear, could fool a fish into thinking he was headed into a mighty current. Relocation of fish to other streams, as experimented at the time Grand Coulee (335 ft.) and Shasta (487 ft.) dams were built, though successful at first, is not considered a sound solution by U.S. Fish and Wildlife when a major run is blocked, since the losses incurred by fish population in the process have to be supplemented from hatcheries. In fact, no fully satisfactory answer to the problem has been arrived at, and although both sides claim gains, the complete solution still lies a long way off; and whereas the Federal Power Commission views the future rather optimistically, utility experts remain sceptical. (*Electrical World*, June 17, 1957, p. 48, 3 pp., 5 ff.)

Planning the Swedish V.H.T. System

A survey is given of the present stage of development of the Swedish V.H.T. transmission system and of its future expansion. The aggregate length of V.H.T. lines in Sweden on Jan. 1, 1957, was 2,714 and 4,237 km. for the 380 kV and 220 kV systems respectively. Investigations have shown that the present transmission capacity of 2,000 MW is likely to increase to 3,000 MW by 1960 and 5,500 MW by 1970, as against the estimated 3,000 and 4,000 MW worked out at the time the first 380 kV line was under consideration. A re-examination of the voltage question has therefore become necessary, and three alternatives have been investigated: (a) maintaining 380 kV for

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new plants; (b) reconstructing the present 380 kV system to 500 kV, all new plants to be designed for this higher tension; (c) keeping the present 380 kV in service while proceeding with the setting up of a 650 kV system. The following variant is also under consideration: two 400 kV d.c. links with a transmission capacity of 1,500 MW each, operating in parallel with a 380 kV system. This would considerably reduce the cost of the line, in comparison with an a.c. line; on the other hand, the necessary large-size and expensive transformers would entail higher manufacturing costs. A further obstacle to the d.c. variant is that it has proved impossible to insert it into the Swedish system's d.c. lines of the above capacity exceeding 800 km. in length. (S. Lalander, *OZE, Oesterreichische Zeitschrift für Elektrizitäts wirtschaft*, Vol. 10, No. 5, May 1957, p. 144, 10 pp., 16 ff.)

Water-Power Development in Orissa

This issue of the undermentioned journal is especially devoted to Irrigation and Power Development in Orissa, and contains, among others, the following articles of water-power interest: "Power Development in Orissa," by R. L. Narayanan, p. 1, 3 pp., with a map of the Orissa Grid; "Power Utilisation in Orissa," by J. M. Patnaik, p. 5, 2 pp.; "Rural Electrification in Orissa," by J. M. Patnaik and Y. Das Choudhary, p. 15, 4 pp.; "Electrical Development in Ganjam District of Orissa," by S. M. Panda, p. 19, 2 pp. The Editorial (p. 23), deals briefly with the general aspects of irrigation and power development in Orissa. (*Indian Journal of Power and River Valley Development*, Vol. VII, No. 1, January 1957.)

Yellow River Basin Multi-purpose Project

The Yellow River, known as "China's Sorrow" in the past, is the second largest river in the country, with a length totalling 4,845 km. from its source in the Chinghai Province to its mouth in the Pohai Bay. It drains an area of 745,000 sq. km., and has an aggregate drop of elevation of 4,368 m. The floods of the Yellow River are notorious and are a constant threat to the safety of the 80 million people inhabiting 250,000 sq. km. of fertile land, not to mention the loss of water and soil in the middle reaches and frequent serious drought in the whole basin. The general multi-purpose plan for the complete harnessing of the river, drawn in 1954 with the assistance of Soviet technicians, covers the following aspects: flood control, irrigation, power generation, navigation, and water and soil conservancy. All these aspects are briefly reviewed and discussed in this article. The plan contemplates the development of the main course of the river as a continuous cascade involving the setting up of no fewer than 46 dams with an aggregate installed capacity of 23 million of kW and a yearly production of 110,000 million kWh, equivalent to ten times the total output of the whole country in 1954. Among these 46 dams, the first-stage projects, scheduled to be completed by 1967, include, in addition to three irrigation dams, two major power schemes—the Sanmen Gorge and Liukia Gorge developments. The Sanmen Gorge is located about 20 km. east of Shenhsien (Honan Province) and its development will include the creation of the largest reservoir on the Yellow River, with a capacity of 36 cu. km. at El. 350 m., the normal high-water level, increasing to 65 cu. km. at El. 360 above Taku datum. One million kW of electric power will be generated, and the corresponding yearly production of 4,600 million kWh will satisfy the industrial, agricultural and other needs of Shensi, Shansi and Honan Provinces. The Liukia Gorge is located 60 km. west of Lanchow, and the dam site is a deep and narrow gorge only 45 m. wide at the water surface. The height of the projected dam reaches 120 m. The capacity of the reservoir will be little short of 5 million cu. m. The capacity of the power station will be the same as at Sanmen Gorge, i.e. a million kW, and the annual energy output of 5,230 million kWh will benefit Lanchow and the neighbouring regions. (Cheng Hsueh-Ming, B.Sc., Bureau of Hydro-electric Development, Ministry of Power Industry, People's Republic of China, *Indian Journal of Power & River Valley Development*, Vol. VII, No. 2, February 1957, p. 5, 4 pp., 2 ff., 1 map.)

Sanaga Development, French Cameroons

The Edea power station, the present equipment of which consists of two 15,500 h.p. turbines operating from a head of 24 m., will be supplemented at first by the addition of a third turbine of 17,000 h.p., and subsequently by the installation of six generating sets, driven each by a 27,000 h.p. turbine, which will provide an aluminium smelter with the electric energy it requires. The ultimate installed capacity of the station will thus be increased to 150,000 kW, and the yearly production will reach 1,200 million kWh. This article briefly describes the extension works to be carried out, and reviews the present stage of the civil-engineering work and of the electro-mechanical installations. (M. Soubrier and J. Mauret, *Travaux*, Vol. 41, No. 271, May 1957, p. 231, 7 pp., 11 ff.)

NOTE. An abstract from a previous article on this French colonial development appeared in our issue of April 1957, p. 157.

U.S.A. Electrical Industry Statistics

The undermentioned journal publishes its 53rd Annual Report on the Electrical Industry of U.S.A. and Canada. Capital expenditures for electric utilities in U.S.A. are scheduled to reach $4,800 millions in 1957, almost 28% more than the $3,800 millions spent in the previous year. Canada plans to spend $485 millions this year, as against $464 millions last year. Of $281 millions required for power generation, hydro will get 75·8%. New capacity additions are detailed by regions and separate figures being given for hydro, steam, internal combustion and geothermal plants. (*Electrical World*, Vol. 147, No. 4, p. 115, 47 pp., 18 graphs.)

Wind Power

A condensed but fairly comprehensive synoptic survey of the various types of windmills designed to act as prime movers to electrical generators. Following a review of all possible methods of harnessing wind power to drive rotary machines and critical considerations on the efficiency and characteristics of each type of windmill, the author draws the conclusion that the propeller-type windmill with its axis parallel to the direction of the wind is the only type which can be applied industrially to good purpose. The various improvements added to the machine are listed, and suitable designs for the main components, e.g., towers, wheels, govern-

ing system, wheel-directing gear, power transmission, etc., are summarised in a table. Designs which are considered the most advantageous as to costs of construction and easiness of operation are discussed in separate paragraphs. (L. Vadot, Consulting Engineer to Etablissements Neyrpic, Grenoble, *La Houille Blanche*, Vol. 12, No. 2, March-April 1957, p. 189, 15 pp., 21 ff.)

Note: An English translation is appended, p. 204, 10 pp.

Czechoslovak Testing Practice

This article gives an account of the tests to which the Skoda Works submit vertical-shaft alternators driven by water turbines, in their up-to-date testing plant. The tests, which are described in detail, apply on the mechanical side to rotor eccentricity, rotor balancing and thrust-bearing friction, while they extend, on the electrical side from the usual measurements (ohmic resistances, especially in stator, temperature rises, reactance values and time constants) to winding insulation, time course of voltage, air-cooling system, etc. (Ing. Jindřich Kramer, *Czechoslovak Heavy Industry*, 1957, No. 6, p. 22, 13 pp., 20 ff.)

Note. This issue of the above mentioned journal is entirely devoted to subjects of water-power interest, and also includes the following articles: "A Brief Survey of Czechoslovak Hydraulic Turbines," by Ing. Pavel Bím; "Research Developments in the Design of High-head Turbines in Czechoslovakia," by Ing. V. Kopecký; "Automation of Hydro-Electric Power Plants," by Ing. Miloslav Syrový. In "Accumulating Hydro-Electric Power Stations," Ing Frant. Kohn deals with pumped-storage plants, and their generating and pumping equipment.

French Electrical Industry

This general survey of the activities of Electricité de France since its foundation in 1946 is included in a special issue of the undermentioned journal devoted to France's industrial development. In addition to the usual economic and statistical information for 1955, this survey contains a section on production and transmission which gives in condensed form an abundance of interesting data. For example, a graph shows the share of seasonal storage, short storage (weekly and daily), and run-of-river plants in the 1955 production: 4,859, 6,806 and 13,910 million kWh respectively. Two maps illustrate the interregional exchanges of energy at high and low-water periods, and show how the direction of the exchanges is reversed from one period to the other, that is to say how thermal plants supplement hydro-electric production in deficient hydrological periods, and hydro- electric works reinforce thermal production when power water is available in abundance. (Dipl. Ing. H. Biefer, *Technische Rundschau*, Vol. 49, No. 34, August 9, 1957, p. 2, 3 pp., 11 ff.)

Simplified Surge-Tank Calculation

The simplified method of surge-tank calculation set out in this paper is based on the assumption that the pressure exerted from the surge tank on the penstock during the initial water-level oscillation (resulting from a variation of the discharge required by the turbines) remains constant. This assumption led to the plotting of two graphs by means of which the volume of water entering or leaving the surge tank at a total or any partial sudden closing or opening of the control valve can be determined. It is further claimed that, when working out estimates in connection with preliminary projects, the two graphs render it possible to obtain at once a first approximation of the volume of the surge tank without resorting to any lengthy trial computation and without having to know accurately in advance the pattern of the surge tank. In addition to these two graphs, two general equations also take into account non-sudden variations of discharge extending over a certain time. (Dr. A. Gardel, *Schweizerische Bauzeitung*, Vol. 75, No. 31, August 3, 1957, p. 485, 5 pp., 6 ff.)

Damping of Surges in Run-of-River Power Systems

Since its very inception, the harnessing of major rivers to power generation in low-head plants has confronted the operating concerns with the problem of controlling the surges which arise in both head- and tailraces when the discharge through the turbines is suddenly cut down. These surges are particularly dangerous on large navigable rivers such as the Rhone, Rhine and Danube, where positive shock waves up to 1·5 m. and negative waves 1·2 m. in height have been measured. High negative surges are the more harmful, since they involve the risk of ships being stranded and, at the same time, impair the running of downstream power stations. Following a review of the various methods of surge control applied in plants operating with a headrace or tailrace canal, or built across the river bed with an adjacent spillway block or weir, the author describes the turbine control system evolved by Escher Wyss Ltd., Zurich, and called " stop control gear." This system proceeds from the control methods in use for many years with Kaplan turbines, which prevent the guiding apparatus from fully closing too quickly, so that a streaming of the water back into the draught tube is impossible, and the speed of the turbine after the switch-off can be kept within a more favourable range. Practical tests at several major power-stations on the Inn, Danube and Rhine have established that the stop control gear substantially restricts the extent of positive and negative surges and, in addition, brings about a quicker stabilisation of the water level in both headrace and tailrace. (M. Hirt & K. Wiedler, *Schweizerische Bauzeitung*, Vol. 75, No. 22, June 1, 1957, p. 327, 6 pp., 8 ff., 7 graphs).

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